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LIMITATIONS OF THE UTTAS HELICOPTER IN PERFORMING TERRAIN FLYING WITH EXTERNAL LOADS

Boeing Vertol Company
P.O. Box 16858
Philadelphia, Penn. 19142

September 1977

Final Report for Period July 1976 - April 1977

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report provides a reasonable quantification of many of the limitations and shortcomings of the UTTAS in terrain flying with external loads. Much of the data was computer generated and has not been confirmed through flight testing. Promising external cargo handling system concepts that will improve the capabilities of the UTTAS in terrain flying with external loads were identified. This work will provide the basis for further design and evaluation efforts of the identified concepts to increase the survivability and utilization of the UTTAS.

Thomas B. Allardice and Major Billy V. Genter of the Military Operations Technology Division served as project engineers for this effort.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Quantitative limitations of the UTTAS helicopter performing terrain flying with external loads have been developed using a fully coupled total force and moment simulation math model of the helicopter and external load. Load sway motion and susceptibility to PIO in night/instrument meteorological conditions were identified as the prime source of these limitations. Masking requirements were determined for various external load configurations including a 105mm howitzer and an A-22 ammo bag. Incorporation of a dual hook suspension or load stabilization coupled with a shortened sling suspension offers the best potential for alleviating the limits identified, while

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Key Words (Continued)

Low Level
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Pilot-Induced Oscillation (PIO)
Around-the-Clock
Tandem Hook Beam Conversion
Night Vision Goggles (NVG)
Short Sling Suspensions
Masking Height Requirements
VFR Collision Plane Avoidance
Load Snag
Visionic Systems
Forward-Looking Infrared (FLIR)

Abstract (Continued)

providing improved masking requirements and reduction in pilot workload. In addition, the levels of maneuverability possible with the present state-of-the-art visionic systems (including FLIR and NVG) were defined for terrain flying during night operations.

PREFACE

This report presents the quantitative limitations of the UTTAS helicopter in performing terrain flying with external loads around the clock. Also provided are analytical results and preliminary designs for concepts which can be utilized in alleviating these limitations.

The work was sponsored by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL), Fort Eustis, Virginia, and was performed by the Boeing Vertol Company, Philadelphia, Pennsylvania, under Contract DAAJ02-76-C-0027, during the period from July 1976 through April 1977.

The Army technical representatives were Mr. T. Allardice and Major B. V. Genter. The contributions of Army personnel to this effort are gratefully acknowledged.

The following Boeing Vertol personnel contributed to this program:

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1.0 SUMMARY

1.1 BACKGROUND AND APPROACH

Current U.S. Army doctrine related to deployment of helicopter units in the high threat environment postulated for mid-intensity battlefields of the future is defined in Field Manual (FM) 90-1, (Reference 1). This document indicates that virtually all helicopters, regardless of type, will be required to terrain fly using techniques described in FM 1-1 (Reference 2), in order to survive and accomplish assigned missions in the hostile environment anticipated. While performing its principal assault mission on the battlefield, the Utility Tactical Transport (UTTAS) aircraft will frequently employ terrain flying techniques when operating near the Forward Edge of the Battle Area (FEBA), in order to avoid direct confrontation with the enemy air defense threat.

Although most assault missions involve the movement of troops, external loads may also be transported efficiently by UTTAS helicopters when necessary. Typical of such missions described in FM 90-1 are the resupply of ammunition to an isolated infantry company engaged in battle, by general support company UTTAS helicopters. Using the 7,000-pound external cargo capability of these aircraft would greatly simplify the tactical resupply missions of this type; prepared landing areas are not required, and minimal time is expended in the forward area to deposit the load.

This report presents the results of a study conducted by Boeing Vertol, under Eustis Directorate, USAAMRDL sponsorship, to assess the limitations of the UTTAS helicopter in performing terrain flying with external loads. In addition to defining limitations, potential solutions are also developed. The study was performed under contract DAAJ02-76-C-0027 between June 1976 and April 1977. A similar study was completed for the CH-47 helicopter under contract DAAJ02-76-C-0028.

Limitations evaluated in the study fall into several broad areas, including:

- Those associated with providing adequate clearance from obstacles while maneuvering close to the terrain.
- Those resulting from load motion and/or aircraft maneuverability and speed capability with the load attached.
- Those related to providing masking (which is the ability to hide the aircraft behind cover during maneuvers).
- Those resulting from aircraft handling qualities, performance, or structural capability.

Specific limitations associated with load acquisition or deposit, and those which accrue from navigational or communication requirements do exist, but were not explored in depth, as these limitations were already being assessed in other U.S. Army research programs.

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1. Field Manual 90-1, EMPLOYMENT OF ARMY AVIATION UNITS IN A HIGH THREAT ENVIRONMENT, Headquarters, Department of the Army, Washington, D.C., 30 September 1976.
2. Field Manual 1-1, TERRAIN FLYING, Headquarters, Department of the Army, Washington, D.C., 1 October 1975.

The UTTAS terrain flying study consisted of two separate phases of activity. The first dealt with the determination of aircraft and system limits, as defined by an unpiloted flight simulation of selected terrain flying maneuvers. With these limitations defined, candidate concepts for cargo and visionics systems, intended to remove as many of the limits as practical, were developed and ranked. These concepts were then reviewed with U.S. Army personnel to provide guidance for the second phase activities.

The second or System Definition phase consisted of executing preliminary design trade studies for the two cargo handling systems selected at the end of Phase I work. These included a tandem hook cargo beam concept for improved load stability, and a single active arm (dual hook) External Load Stabilization System concept. Study emphasis was placed on developing a lightweight jettisonable version of the tandem hook beam.

1.2 TERRAIN FLYING MANEUVERS

Helicopter terrain flying is normally divided into the three separate modes of operation illustrated in Figure 1. These include:

- Nap-of-the-Earth (NOE) flight – where the aircraft generally tries to stay masked below available cover by flying around obstacles.

- Contour flying – where the helicopter remains masked whenever possible during maneuvers, but flies over obstacles which are not easily flown around.

- Low-level flight – where the aircraft flies above all obstacles at relatively constant airspeed and altitude.

Rigorous definitions for each terrain flying mode have varied from time to time over the past few years, as battle tactics changed. At present, the NOE and contour modes are both generally understood to include maneuvers in which airspeed and altitude may be varied to avoid obstacles. Rigid distinction between maneuvers and flight modes is not important, however, when determining the capability of an aircraft to successfully terrain fly to complete its mission. Accordingly, a series of maneuvers were chosen for the terrain flying study (and then grouped as shown in Figure 1), which were thought to best illustrate the varied nature of the obstacles which might be encountered on a typical terrain flight.

Maneuvers selected for evaluation were:

- THE LONGITUDINAL DASH – in which the aircraft is accelerated from a hover to rapidly traverse an area where cover may be lacking. The acceleration phase is followed by a rapid deceleration to a masked hover.

- THE LATERAL JINK – which is similar to the longitudinal dash, but is executed in a sideward rather than forward direction.

- THE LATERAL TERRAIN AVOIDANCE MANEUVER where the helicopter performs a coordinated turn and reversal followed by roll-out to continue straight ahead after avoiding the obstacle. This maneuver was not simulated for the UTTAS aircraft, but was

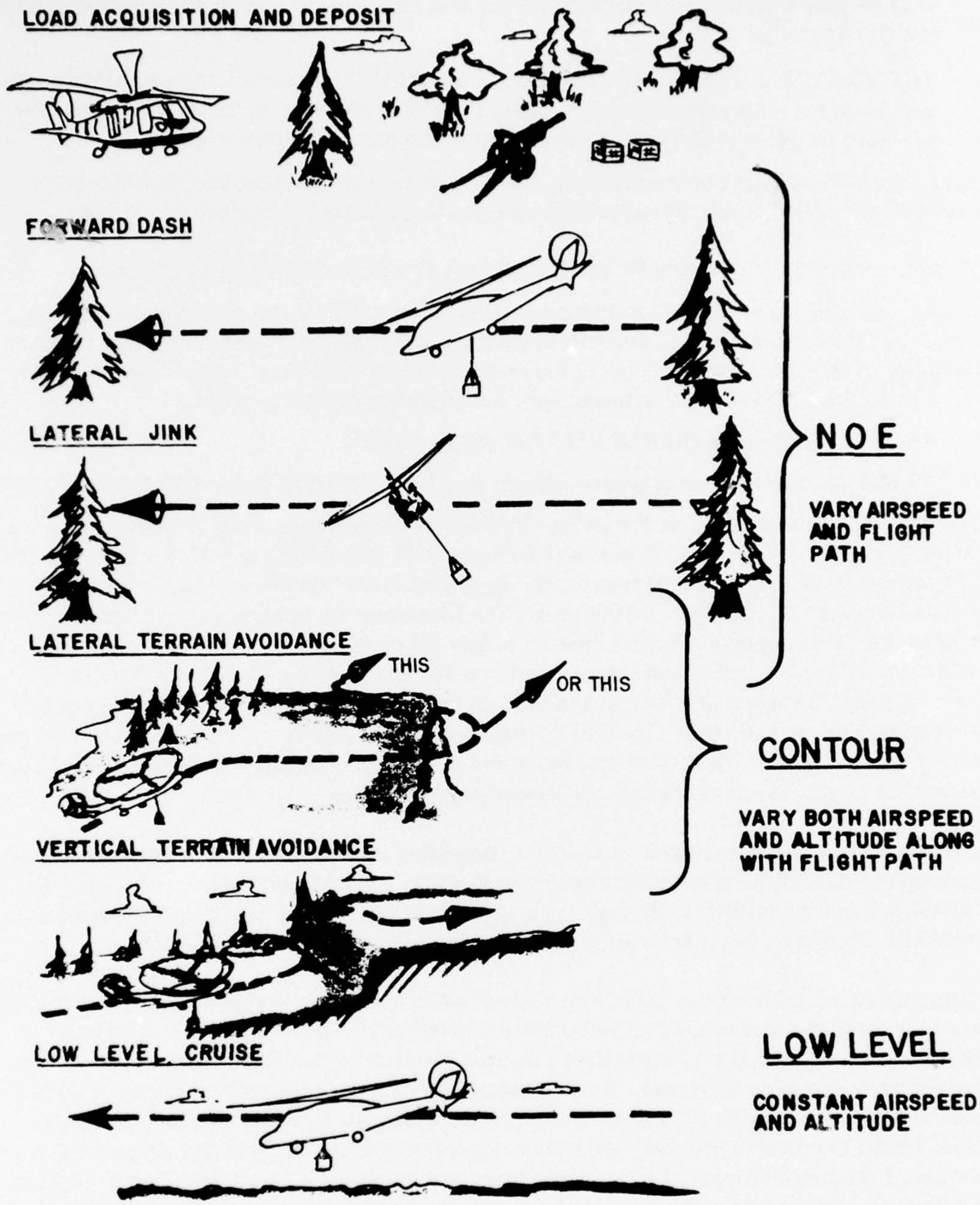

FIGURE 1. TERRAIN FLIGHT DEFINITIONS

evaluated extensively in the terrain flying study performed for the CH-47 (Reference 3). UTTAS lateral terrain avoidance capability is expected to be similar to that developed in the CH-47 study.

- THE VERTICAL TERRAIN AVOIDANCE MANEUVER in which the aircraft executes a maximum performance pull-up to avoid a cliff-like obstacle, followed by a push-over to return to initial cruise altitude above terrain on top of the obstacle.

Low-level cruise was evaluated separately, since no maneuvering is involved, in order to determine masking and speed characteristics with the various load combinations carried.

1.3 ANALYSIS OF TERRAIN FLYING CAPABILITY (For Day/VFR Conditions)

A comprehensive total force computer simulation of the UTTAS and its flight characteristics with external loads was used to quantitatively assess the masking, maneuverability, and speed capability of the aircraft as it executed the maneuvers just described. Each was initially performed with baseline internal payloads, with the aircraft ballasted to either:

- 15,080 pounds – the UH-61A (UTTAS) design weight
- 19,500 pounds – which is approximately equivalent to a 500 fpm vertical climb capability

After completing evaluation of the various internal cargo configurations, all maneuvers were repeated with an A-22 ammunition bag (1,875 pounds), and carried on a single standard 18.5 foot combination sling-chain leg suspension illustrated in the top left-hand corner of Figure 2. An alternate load consisting of a 105mm-M101A1-howitzer (4,780 pounds) with piggyback A-22 pack (1,875 pounds) was also flown through the terrain maneuver series. This load utilizes a single-point suspension, made up of one 15 foot and two 14 foot standard nylon-chain leg slings, arranged as shown at the bottom left corner of Figure 2. Both loads were selected as typical of the type that UTTAS helicopters might carry externally while performing terrain flying missions like those discussed in FM 90-1. Also, the aircraft and load weight were selected to be equivalent to the internal loaded configurations.

Principal results of the maneuver evaluations comparing internal load baselines with external loads on standard suspensions are summarized in Table 1 (along with information for other configurations covered later). This chart ranks the relative effectiveness of transporting loads externally, against an internal baseline for each of the three terrain flight modes.

Numerical values given in the table show the percent degradation in either masking, maneuverability, or speed realized when the load is carried externally. These numbers represent an average taken for all types of maneuvers executed for each terrain flight mode (see Figure 1 for maneuver grouping by mode). As an illustrative example of the NOE masking at 15,080 pounds design weight, the 67.5 percent assessment represents a ratio of the additional external height required to internal load height requirement compiled from an unweighted average of the overall height of aircraft and load, and minimum altitude required to execute the dash, and lateral jink maneuvers. In addition, the configurations are also ordered from one to four by the number in parentheses, with the value one representing the configuration with the least degradation.

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3. Alansky, I.B., Davis, J. M., Garnett, T., LIMITATIONS OF THE CH-47 HELICOPTER IN PERFORMING TERRAIN FLYING WITH EXTERNAL LOADS, Draft USAAMRDL Report, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, April 1977.

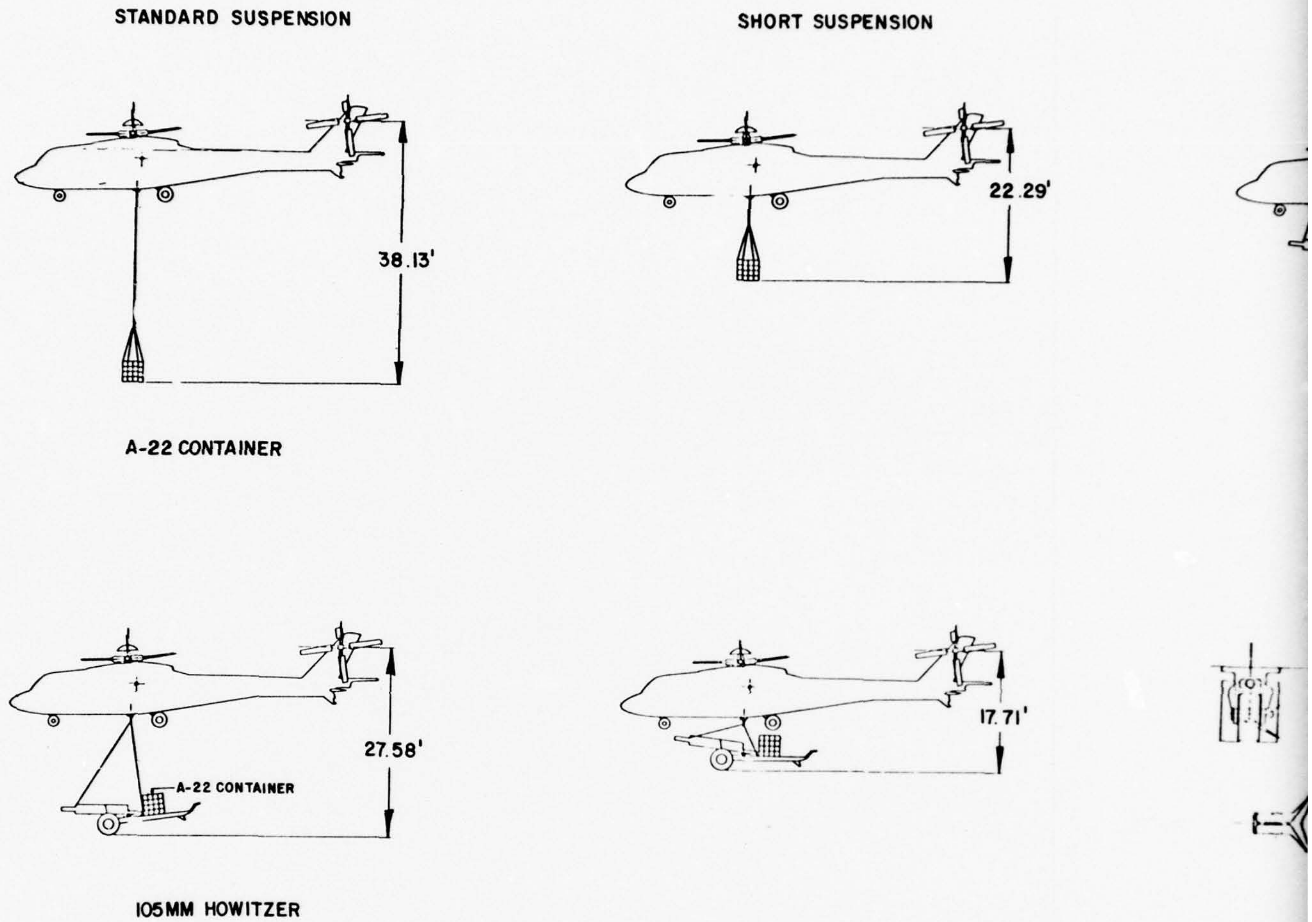

FIGURE 2. LOAD CONFIGURATIONS FOR UTTAS TERRAI

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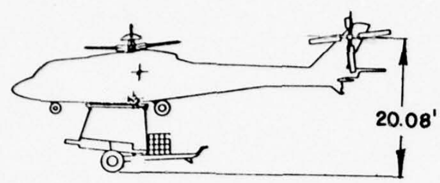
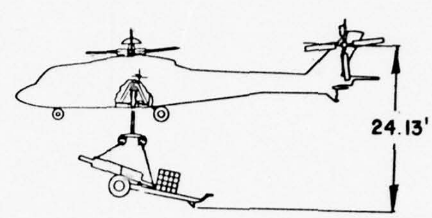
22.29'

DUAL HOOK BEAM

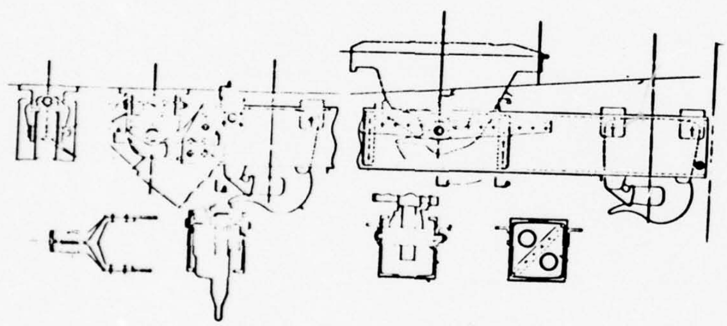


LOAD STABILIZATION
(ACTIVE ARM SUSPENSION)



DETAIL OF DUAL HOOK BEAM

2.71'



OR UTTAS TERRAIN FLYING STUDY

TABLE I. UTTAS TERRAIN FLYING EFFECTIVENESS

Gross weight	Load	Configuration	Nap of the Earth: Masking	Nap of the Earth: Maneuverability	Contour: Masking	Contour: Maneuverability	Low Level: Minimum Cruise CG Altitude	Low Level: Speed	Night/IMC PIO Susceptability
15,080 LB GR WT		INTERNAL LOAD BASELINE	0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
15,080 LB GR WT	A22 AMMO BAG	STD SINGLE POINT SUSPENSION	67.5% (3)	44.2% (3)	43% (3)	10% (3)	229% (3)	6% (1)	HIGH WITH INCREASED LOAD WEIGHT
15,080 LB GR WT	A22 AMMO BAG	STD SINGLE POINT SUSPENSION WITH LSS	69.5% (4)	22% (1)	43% (3)	10% (3)	241% (4)	8% (4)	NEGLIGIBLE
15,080 LB GR WT	A22 AMMO BAG	REVISED SHORT SUSPENSION	3.5% (1)	72% (4)	14% (1)	9% (1)	110% (1)	6% (1)	HIGH WITH INCREASED LOAD WEIGHT
15,080 LB GR WT	A22 AMMO BAG	REVISED SHORT SUSPENSION WITH LSS	9% (2)	22% (1)	14% (1)	9% (1)	110% (1)	7% (3)	NEGLIGIBLE
19,500 LB GR WT		INTERNAL LOAD BASELINE	0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
19,500 LB GR WT	105MM HOWITZER + A22	STD SINGLE POINT SUSPENSION	25% (3)	29% (4)	22% (3)	5% (3)	177% (3)	31% (2)	HIGH
19,500 LB GR WT	105MM HOWITZER + A22	STD SINGLE POINT SUSPENSION WITH LSS	25% (3)	23% (1)	22% (3)	5% (3)	177% (3)	33% (4)	NEGLIGIBLE
19,500 LB GR WT	105MM HOWITZER + A22	REVISED SHORT SUSPENSION	17% BETTER (1)	23% (1)	1.5% (1)	1.0% (1)	72% (1)	28% (1)	HIGH
19,500 LB GR WT	105MM HOWITZER + A22	REVISED SHORT SUSPENSION WITH LSS	17% BETTER (1)	23% (1)	1.5% (1)	1.0% (1)	72% (1)	31% (2)	NEGLIGIBLE

% PERFORMANCE DEGRADATION FROM INTERNAL LOADED BASELINE

NUMERICAL ORDERING

This ranking assumes equal weighting for all terrain flight maneuvers, since no specific mission scenario was followed in evaluating overall capability. Ranking schemes applied in this study may be adjusted in future application of the results to fit any desired terrain flight scenario, by simply applying the appropriate weighting factors.

Returning to the table, it is apparent from the standard suspension results that performing the various terrain maneuvers with external loads degrades the aircraft's capability appreciably. Masking suffers anywhere from 43 to 67 percent in the NOE and contour modes due to the addition of an external load. Maneuverability is also restricted, particularly for the lighter A-22 slingload.

A number of schemes for recovery of the internal load capability while flying with external cargo were considered, and several were analyzed. The most promising of these are illustrated in the center and right-hand sketches in Figure 2. Short suspensions and automatic load stabilization concepts were evaluated for each terrain flight maneuver and the tandem hook beam approach was developed for improving flight with all types of external loads; especially those exhibiting poor aerodynamic or inertial stability characteristics. Although the selected A-22 and 105mm howitzer loads were found to be relatively free of such stability problems on their single-point suspensions, other load configurations such as the CONEX box display strong aerodynamic instabilities and would therefore benefit from the yaw constraint provided by the tandem hook beam configuration.

Short Slings – Initial attempts to improve overall performance by shortening the external slingload suspension were relatively successful in the area of masking, as shown in Table 1. For example, in NOE flight, the A-22 load exhibited a 67.5 percent degradation in masking with the standard suspension, and only 3.5 percent with the shortened sling. These masking requirements reflect the effect of any maneuverability reductions. Masking comparisons without any maneuverability impact are shown by the overall heights noted in Figure 2. Maneuverability was further restricted than with the standard suspension. Load motion was not significantly attenuated with the short slings, and resulted in fuselage/load interference with milder maneuvers because the load was closer to the aircraft bottom. In the case of the howitzer load, this reduction in short sling NOE maneuverability resulted in a 17 percent improvement in masking (rather than a decrease as with other configurations).

Automatic Load Stabilization – An alternative solution for alleviating the maneuverability problems was to employ a single active arm load stabilization system, of the type shown at the right in Figure 2. This active arm (AAELSS) concept is an outgrowth of two earlier developmental systems which were extensively flight tested on CH-47 type helicopters in 1972 and 1975 (References 4 and 5). The single arm approach for UTTAS would be hydraulically powered, and would employ an inverted "T" lower arm arrangement with a dual cargo hook configuration for yaw constraint of the load.

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4. Smith, J.H., Allen, E.M., and Vensil, D., DESIGN, FABRICATION, AND FLIGHT TEST OF THE ACTIVE ARM EXTERNAL LOAD STABILIZATION SYSTEM FOR CARGO HANDLING HELICOPTERS, Boeing Vertol Company; USAAMRDL Report 73-73, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, September 1973, AD 773025.

5. Garnett, T. S. Jr., Smith, J. H., ACTIVE ARM (EXTERNAL CARGO) STABILIZATION SYSTEM FLIGHT DEMONSTRATION, Boeing Vertol Company; USAAMRDL Report 76-23, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, September 1976, AD A031062.

As illustrated in Table 1, active arm stabilization used with a short suspension improves NOE maneuverability appreciably, when compared to the standard suspension performance with the A-22 load. The slight degradation in masking shown in the NOE Summary when load stabilization is used, occurs because aircraft pitch and roll maneuverability has been restored with AAELSS, and thus more height is required to hide the overall aircraft/load combination.

The estimated weight of a single arm AAELSS for UTTAS application would be on the order of 300 to 350 pounds, based upon information developed for a dual arm system in the CH-47 terrain flying study.

Tandem Hook Beam Conversion – A scheme for converting the single UTTAS cargo hook into a tandem configuration in order to reduce load yaw swaying motion, and thus improve maneuverability, was developed. Details of the beam and hook arrangement are shown in the lower right hand sketch in Figure 2. This system is attached to the helicopter through the standard aircraft cargo hook at the rear, with the front end captured by a special spherical fitting which permits the beam to rotate laterally to follow load motion. Both tandem hooks are released together for load deposit, and the entire beam can be jettisoned in an emergency by opening the main cargo hook.

In addition to providing yaw constraint for loads which tend to rotate in flight, the tandem hook beam would also be very useful in helping the pilot deposit loads with precision. Capability for placing artillery pieces on the ground, aligned with approximate headings desired for firing, would enhance the overall tactical utilization of the aircraft for carrying loads externally. The overall weight of the tandem hook beam conversion is potentially very light, totaling only 132 pounds for the entire installation. Approximately 120 pounds of this is removable, and the remainder is a fixed structure built into the aircraft.

Longitudinal hook separation along the beam has been sized to handle the failure of a single sling suspension on the UH-61A helicopter. Aircraft control power with the hingeless rotor is adequate to handle such failures, but should be checked for application of this concept on other aircraft with conventional articulated rotor systems and different cargo hook locations.

Because of the relatively high beneficial gain in aircraft maneuverability and speed expected from its use, and because of its low weight penalty and cost, it is recommended that development of the tandem hook beam concept be continued for application on the UTTAS aircraft. Automatic load stabilization also shows promise for the UTTAS, particularly for Night and IMC operations as detailed in Section 1.5, and needs to be considered if these operations are required. In addition to these analyzed concepts, future consideration should be given to a device that would permit an external load to be snubbed to the underside of the aircraft to minimize masking and to maximize maneuverability. Such a concept has been developed for use on the CH-47 (Reference 3).

1.4 EVALUATION OF A TYPICAL LONGITUDINAL DASH

Summary information presented in Table 1 was generated from detailed analytical simulations of each terrain flight maneuver. An example of the type of data developed during the study is shown in Figures 3, 4, and 5 for a typical longitudinal dash. Figure 3 represents capability with an internal load, and Figures 4 and 5 depict performance with the combined 105mm howitzer/A-22 piggyback slingload on long and short slings, both with and without active arm automatic load stabilization. Similar presentations were developed for all load-maneuver combinations studied.

Internal Load Baseline – At the top of Figure 3 are the dash distances and time required to complete the maneuver for four different fuselage pitch attitude changes varying from 5 to 20 degrees. For a constant dash length, increasing the pitch attitude rotation reduces maneuver time, but this also increases the masking height requirement as shown in the center plot in Figure 3. Masking height reflects the maximum distance from the uppermost rotor tip (usually the tail rotor) down to the lowest point on the aircraft experienced during the maneuver.

Maximum speeds achieved during the acceleration phase are plotted at the bottom of the figure. Crossplots of these velocities at 30 and 60 knots appear at the top of the figure. The significance of these two speeds is covered later in discussion of night and IMC flight characteristics.

External Loads – Dash lengths and times for the longitudinal dash maneuver flown with external loads are illustrated at the top of Figure 4. Beneath this plot are depictions of load sway angle for the long and short sling suspensions, and associated sway angle limits beyond which load excursions are not permitted. Translating the sway angle limits into maximum body attitudes permitted during the maneuver reveals that maneuverability is reduced roughly 25 percent when flying with the 105mm howitzer payload. Maneuverability reduction is more severe for the A-22 load, exceeding 50 percent for the short suspension configuration.

This reduction in maneuvering capability, and an increase of 10 to 14 feet in masking height required to complete the maneuver with external cargo (shown at the top of Figure 5), adds substantially to potential aircraft vulnerability on a hostile battlefield. The terrain flying study did not evaluate vulnerability essentially, but has generated the baseline data upon which an analysis of this type could be based.

Returning to the load sway curves shown in the middle of Figure 4, it is apparent that an automatic load stabilization system has the potential for reducing load motion substantially. This improvement, in turn, will allow the aircraft to regain lost maneuverability, as shown at the top of the figure. The system also eliminates the possibility of encountering longitudinal pilot-induced oscillation (PIO) of the load in night or instrument weather as discussed below

1.5 IMPACT OF NIGHT AND IMC CONDITIONS ON TERRAIN FLIGHT

Tendency for PIO when carrying certain loads in reduced visibility conditions is well known from experimental flight test work and field experience with different load suspensions flown on both tandem and single rotor helicopters. The testing documented in References 4 and 5 has shown that PIO can occur whenever load motions create longitudinal accelerations perceived by the pilot that exceed ±0.05g. Such accelerations produce a confusing motion cue pattern for the pilot; this in turn increases his workload appreciably and may result in control inputs which excite rather than attenuate load motion. For successful terrain flying, it is imperative that load motion not create additional pilot workload.

PIO potential for all terrain maneuvers was evaluated by comparing levels of alternating longitudinal acceleration with the 0.05g criteria, as shown at the bottom of Figure 5. Results of this analysis showed potential reduced visibility PIO boundaries to fall somewhat below the load sway limits, with maximum aircraft attitude changes restricted to between 8 and 10 degrees, instead of to approximately 15 degrees in VMC conditions for the howitzer load. This heavier load is more susceptible to PIO than the A-22 bag, since accelerations transmitted into the aircraft are directly proportional to the load/aircraft weight ratio. Automatic load stabilization eliminates the possibility of encountering load PIO. Susceptibility to night- or IMC-associated PIO of the load is annotated for all cargo configurations studied in the right-hand column of Table 1.

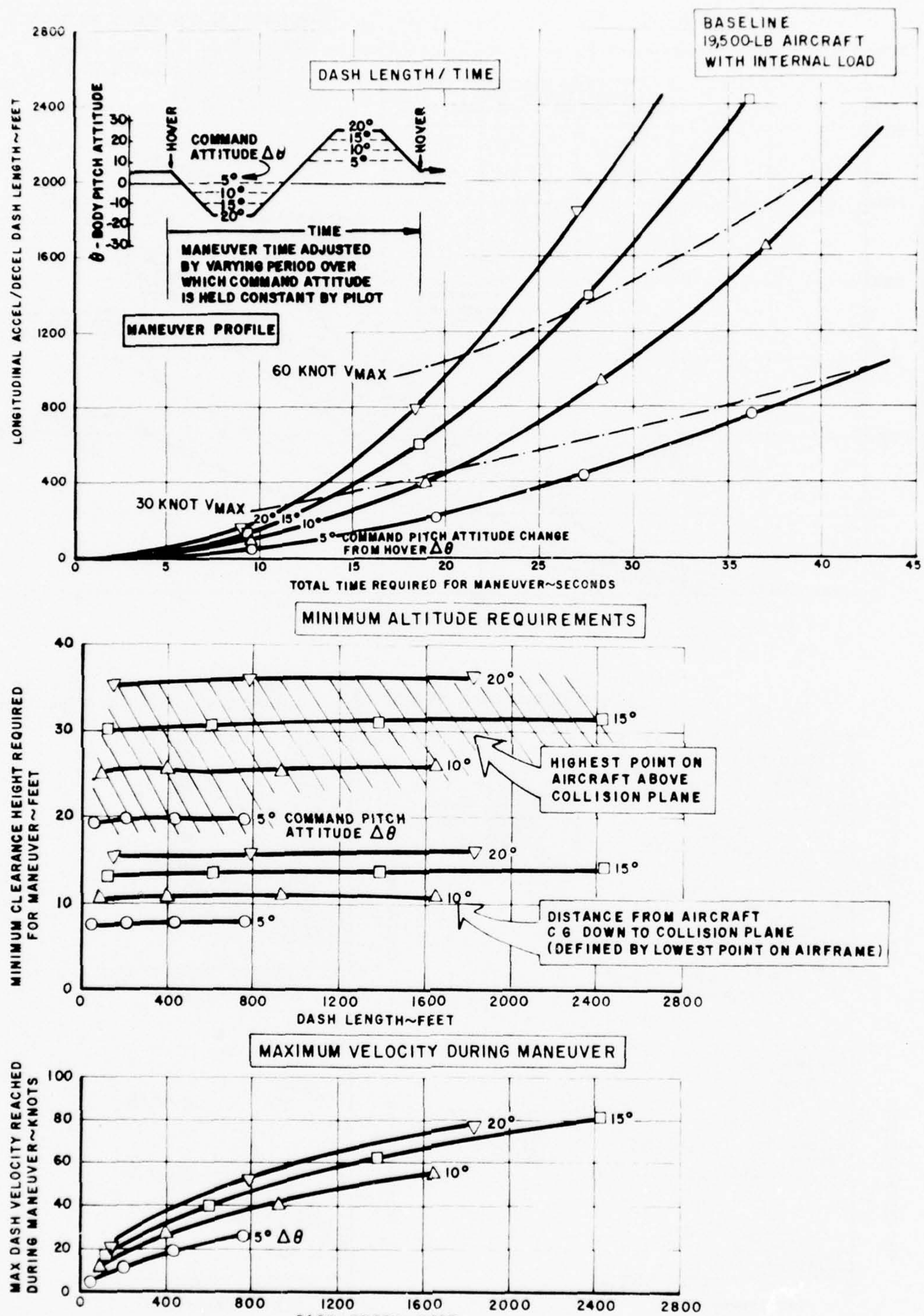


FIGURE 3. UTTAS LONGITUDINAL DASH WITH INTERNAL LOAD

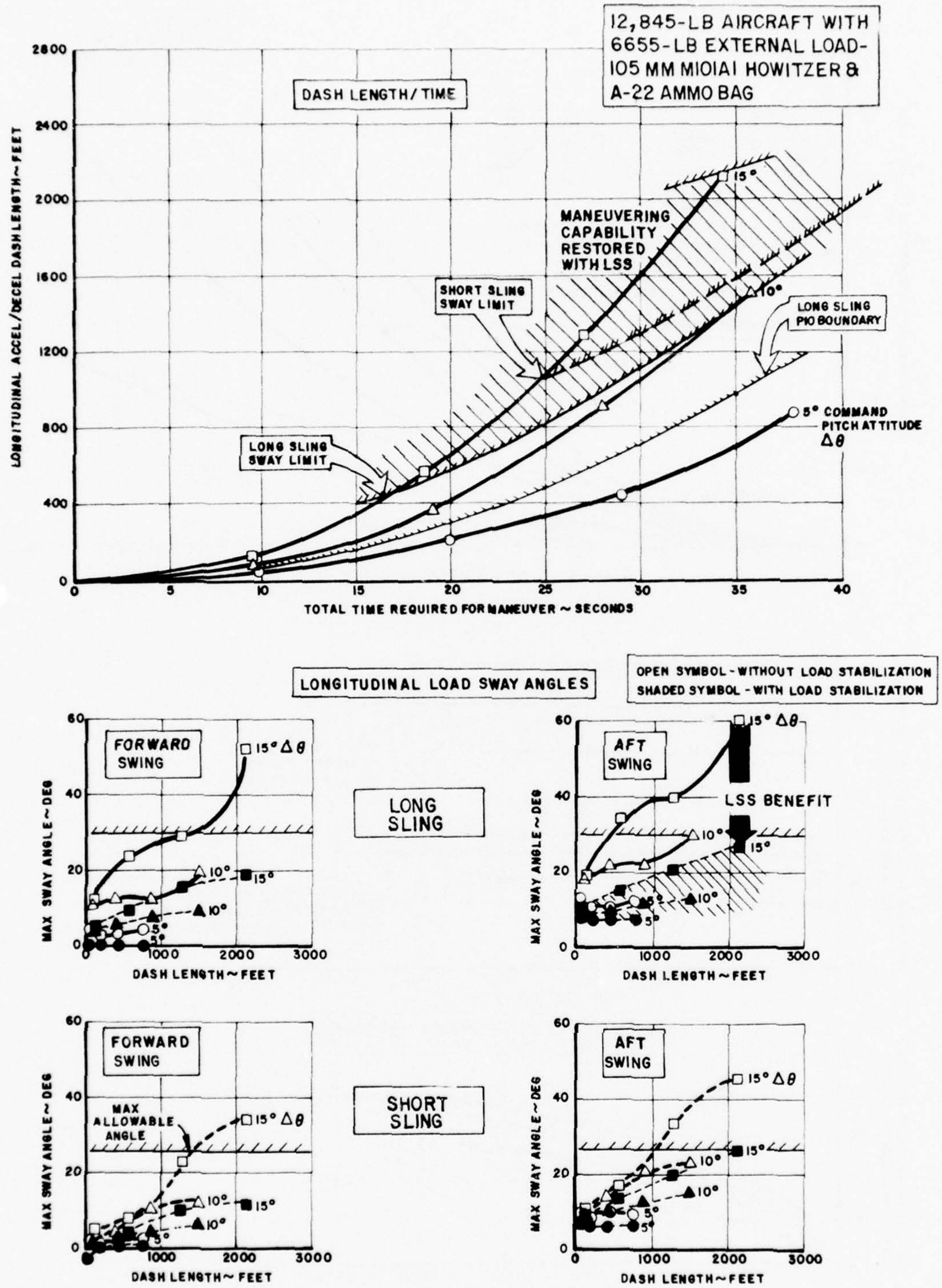
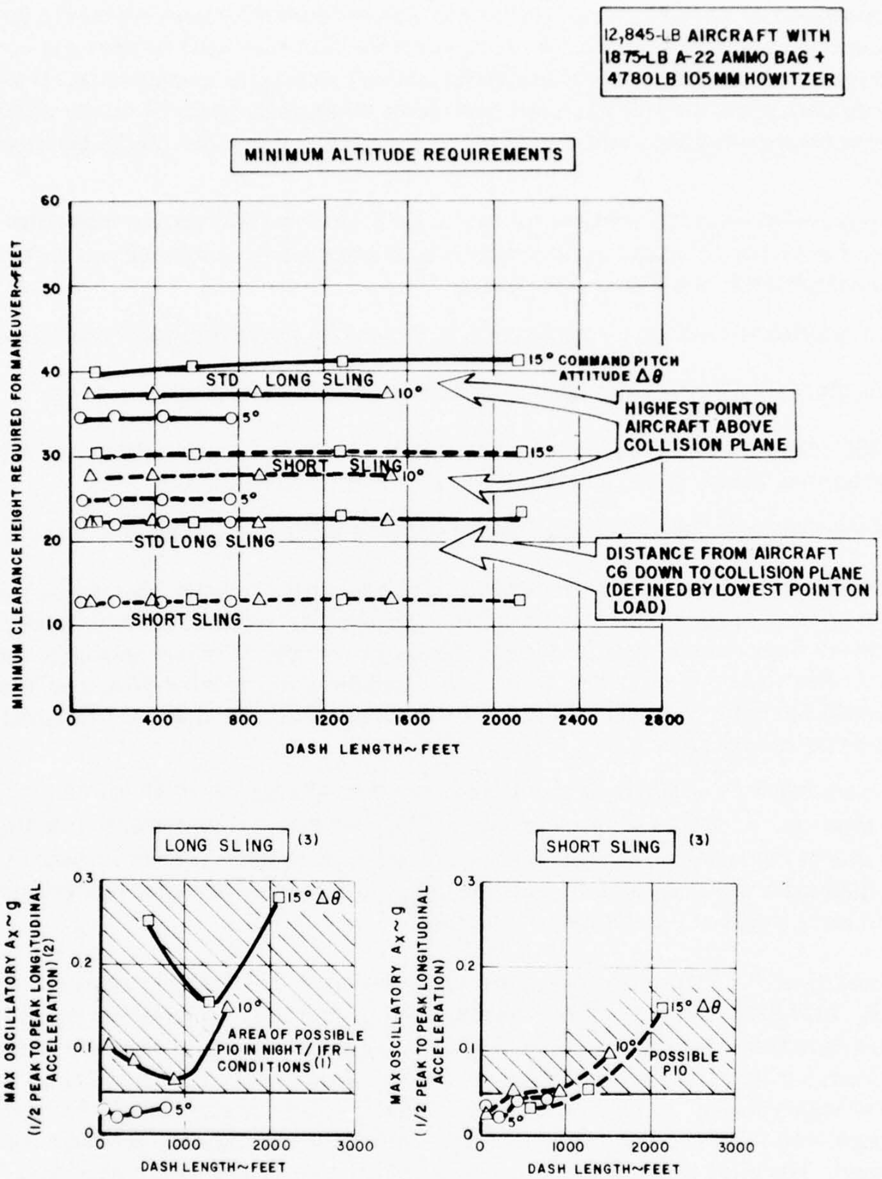


FIGURE 4. UTTAS LONGITUDINAL DASH WITH EXTERNAL LOAD



NOTES:

1. CRITERIA FOR PIO BASED ON $A_X = 0.05g$, FROM AAELSS I FLIGHT TEST RESULTS WITH PILOT UNDER HOOD (SIMULATED IFR)
2. 1/2 PEAK TO PEAK A_X RESULTING FROM LOAD SWAY ONLY
3. STANDARD LONG SLING 14.6 FT, SHORT SLING 5.15 FT

FIGURE 5. UTTAS HEIGHT REQUIREMENTS AND PIO SUSCEPTIBILITY WITH EXTERNAL LOAD

At present, it is possible to perform some limited nighttime terrain missions with external loads. This capability varies from load to load, and depends heavily upon such things as available moon or starlight, pilot proficiency, and/or familiarity with courses to be traversed. Of necessity, speeds flown would be quite low since obstacles must be seen and control inputs introduced soon enough to effect successful obstacle avoidance maneuvering. Obviously, on a perfectly dark night (or in IMC conditions), some additional capability to see potential obstacles must be provided before terrain flying in the NOE and contour modes becomes a practical reality.

To explore what might be possible for future UTTAS night/IMC terrain flight operations, a survey of available visionics (vision systems) with associated capabilities was performed. Results are depicted in the Figure 6 bar chart.

The three systems selected for application in the terrain flying maneuver analysis were:

- Night Vision Goggles (NVG) – with 40-degree field of view
- 360 Line Forward-Looking Infrared (FLIR) – with 30-degree x 40-degree FOV helmet-mounted display (also called PNVS – pilot night vision system)
- Laser Obstacle Terrain Avoidance and Warning System (LOTAWS) – for wire avoidance

The NVG and FLIR systems permit the pilot to see larger obstacles, thereby permitting flightpath control under reduced visibility conditions. Experimental versions of these systems have been extensively flight tested, with results published in a number of documents including References 6 and 7. Both systems are being refined for installation on the YAH-64 armed attack helicopter, and would therefore be likely candidates for future application in any UTTAS nighttime terrain flying visionics package.

Each is essentially a visible light or infrared amplification device which is intended primarily for night time use. FLIR has some capability in IMC conditions, but performance degrades in cloud due to cold-soaking effects. Microwave radiation systems such as Forward Looking Microwave Radiometry (FLMRAD) noted in Figure 6, will be more effective for IMC work, but are only in early stages of development at present.

The resolution of FLIR or NVG systems is not sufficient for detecting wires in the path of the aircraft. LOTAWS, currently under development by the U.S. Army, offers the most potential for wire detection. Although LOTAWS is an active system, it could easily be operated in burst from a trigger (on the aircraft control stick). As envisioned for application in a terrain-flying visionics display, the LOTAWS image could be superimposed on the FLIR display, and then used with some type of image holding feature which is updated each time the trigger is depressed. The pilot would look ahead for wires as often as he thought necessary, but would not be constrained to continuous LOTAWS use in areas where the air defense threat was high.

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6. Bauer, R. W., Petit, G. D., AIR SCOUT NIGHT GOGGLE TEST, Technical Memorandum 14-74, AM CMS Code 612106.11.81900, U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, July 1974.

7. Stich, K., Palmer, J., INVESTIGATION OF NIGHT VISION EQUIPMENT AS A HELICOPTER FLIGHT AID: LOW LEVEL NIGHT OPERATIONS WITH LLLTV AND FLIR SYSTEMS, U. S. Army Electronics Command, Night Vision Laboratory, Fort Belvoir, Virginia, November 1973.

CANDIDATES		VMC CAPABILITY					IMC CAPABILITY			SYSTEM STATUS/COST
SYSTEM	TYPE	DAY	1/2 MOON	1/4 MOON	STARLIGHT (CLOUDLESS)	TOTAL DARKNESS	BROAD TERRAIN FEATURES	SMALL OBSTACLE + RANGE INFO	WIRE DETECTION	
NAKED EYE		EYE								
NIGHT VISION GOGGLES (NVG)	PASSIVE		NVG							• IN PRODUCTION • COST ≈ $10,000
LOW LIGHT LEVEL TV (LLL-TV)	PASSIVE		LLL-TV							• PROTOTYPES FLYING
FORWARD-LOOKING INFARED (FLIR)	PASSIVE		FLIR							• PROTOTYPE FLYING • AAH PROTOTYPES UNDER DEVELOPMENT • COST ≈ $60-80,000
FORWARD-LOOKING MICROWAVE RADIOMETRY (FLMRAD)	PASSIVE		FLMRAD							• EARLY STAGES OF DEVELOPMENT
LASER OBSTACLE TERRAIN AVOIDANCE & WARNING SYS. (LOTAWS)	ACTIVE	LOTAWS								• PROTOTYPE CONCEPT FLOWN ON CH-53 FOR WIRE DETECTION
RADAR	ACTIVE		RADAR							• PROTOTYPES FLOWN • NOE/CONTOUR APPLICATIONS QUESTIONABLE

FIGURE 6. POTENTIAL VISIBILITY IMPROVEMENT CANDIDATES

Terrain-following or avoidance radar systems were not considered due to their continuous active nature, and to obvious problems in presenting the pilot with a display suitable for NOE maneuvering.

To quantify how well the terrain flying maneuvers might be performed while using the visionics systems just described, range capability for each device was developed for several different obstacle (target) sizes at various levels of probability. Using an arbitrary level of 75-percent probability of being able to see two selected obstacles of different size, range information was generated for the three systems. This data was then plotted on the various maneuver distance curves as shown in the Figure 7 longitudinal dash example.

In interpreting the plot, it is useful to note that the pilot would be able to see at least up to the distances annotated for each system 75 percent of the time. That is, with NVG, he could see a tracked vehicle up to about 320 feet, and small terrain features to 480 feet, etc. Since it is assumed that the pilot must be able to see his destination before starting a maximum performance maneuver of the type plotted, the maneuver envelope available with the vision system is then simply the portion of the curve below the vision range line.

With the 75 percent probability assumption in mind, NVGs provide maneuver capability to roughly 30 knots, and FLIR to 60 knots or more. Speed capabilities for the other maneuvers examined were also in this 30-60-knot range. This fact may seem somewhat conservative in view of actual field testing flown at higher speeds. The apparent discrepancy is resolved, however, when it is realized that most night terrain flying,because of training safety considerations,has taken place in better weather and lighting conditions which have substantially lower probability of occurrence than the 75 percent assumed for this study. In addition, most night "terrain flight" testing has been conducted in the low level rather than true NOE or contour modes.

1.6 LOAD SNAG

In addition to assessing day VFR and night/IMC potential for terrain flight, the problem of how to handle load snags was also addressed during the study. The question posed was whether or not the aircraft would crash if the load was snagged on some obstacles, and if it did not impact the ground, how much time would be available to effect successful jettison.

Two types of snags were looked at for the UH-61A helicopter: one where maximum hook loads (37,000 pounds) are exceeded, and the suspension or hook fails, and a second type where loads approach the maximum allowable as if the load were being dragged through trees, etc. In the case where the hook or slings break, very little altitude is lost during recovery, and the aircraft will probably fly out of the maneuver without requiring excessive pilot corrective control inputs.

On the other hand, if the suspension remains intact and no pilot corrective action is taken, the aircraft will descend, rotate nose down, and hit the load in about 1-1/2 seconds for the long sling configuration and in one second with the short. Limited analysis indicates that this descent and pitch rotation can, however, be controlled with longitudinal stick and collective control inputs,until either the load becomes free, or the pilot manually jettisons the load. Additional work must be done to firmly establish whether or not the UH-60A aircraft would be recoverable following a load snag, and if so, whether or not automatic load jettison capability is necessary to prevent aircraft collision with the ground or load.

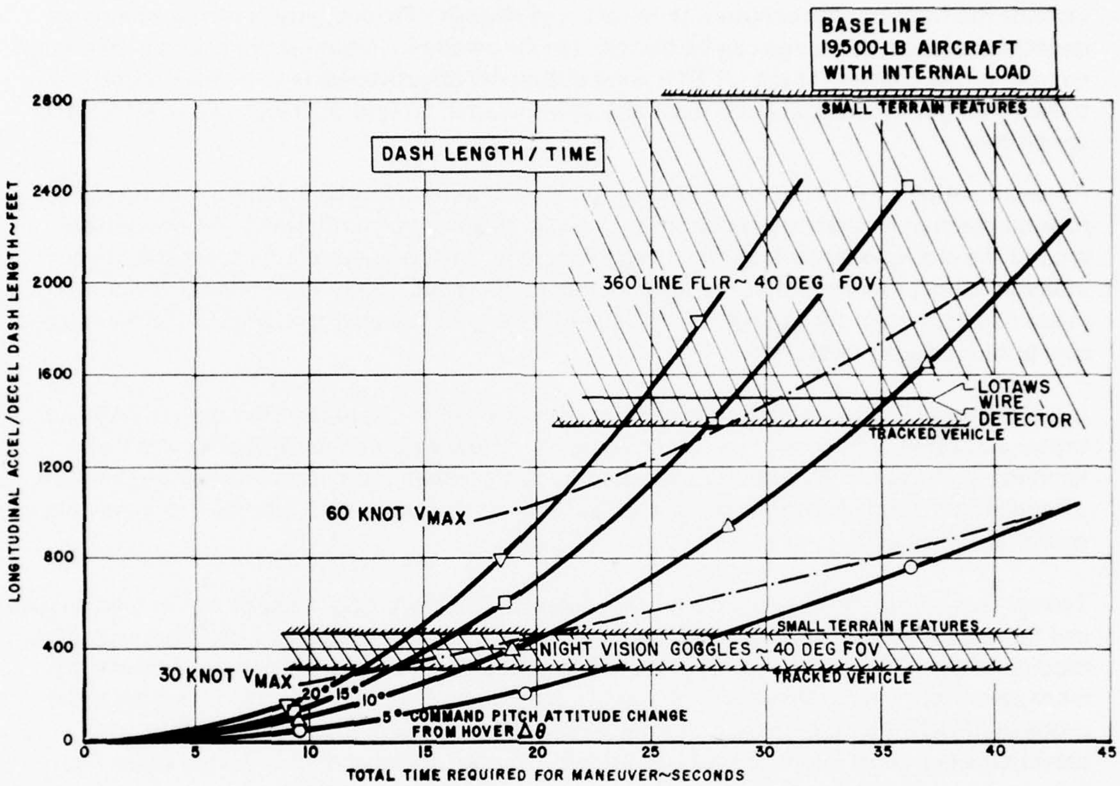

FIGURE 7. DASH POTENTIAL WITH NIGHT VISION SYSTEMS

2.0 INTRODUCTION

Current Army doctrine, as defined in References 1 and 2, provides for the employment of the UTTAS helicopter in a combat support role on a mid-intensity battlefield. Terrain flying with the UTTAS will be necessary if it is to survive and complete its mission in the high threat environment. Carrying cargo externally in this environment is highly desirable even if internal loading is a viable alternative. Combat vulnerability is minimized; external loading reduces to seconds the forward area exposure time for cargo deposit. Productivity is increased as large quantities of prerigged cargo can be transported externally in minimum time with a minimum number of helicopters. If the UTTAS combat support effectiveness is to be maximized, then terrain flying with external loads must also be conducted around the clock and in all weather conditions.

An examination of the concept of terrain flying with external loads indicates that successful mission conduct is currently restricted by a broad spectrum of limitations. To provide an around the clock, external load flight capability, the helicopter system must satisfactorily integrate all requirements that permit the pilot to hover accurately for load acquisition, to safely depart, terrain fly and approach his destination, and deposit the cargo; all within acceptable pilot workload levels.

Limitations during load hookup result from the pilot's inability to position the UTTAS helicopter accurately either horizontally or vertically in low visibility conditions due to both handling qualities and to visibility considerations. Potential improvements can be achieved through flight-control modifications, such as inertial velocity control, limited crewman control, and/or visibility aids.

Terrain flying limitations result from many factors. The helicopter must be flown high enough and far enough from obstacles to insure load-to-obstacle or ground clearance. When masking requirements are taken into account, maneuverability limits result. Masking constraints are more severe with an external load. A snagged load on a wire or other obstacle is a potential problem in NOE flight, perhaps requiring revised hook release jettison capability or wire detection electronics to prevent loss of aircraft. Aircraft speed and low altitude capability is limited by aerodynamic load instabilities and reduced maneuverability due to potential load to airframe collisions.

Improvements can result from shortening sling restraints which minimize overall size and load instability, and through application of automatic load stabilization which prevents load-to-aircraft collisions during large pitch and roll maneuvers, and at the same time improves flying qualities.

Further speed and low altitude terrain flight limitations result from reduced visibility during all ambient night lighting conditions and IMC. Load motion creates aircraft linear accelerations which represent a confusing motion cue pattern to the pilot under reduced visibility. Flight testing has shown that the pilot can interact in a destabilizing fashion when responding to these cues, resulting in pilot-induced oscillations (PIO).

The pilot also requires visual information as close to day VFR as possible in order to take cover, maneuver to avoid obstacles enroute, deliver the load, and return to base. The UTTAS helicopter currently employs no visual enhancement systems. Improved capability can be

achieved through passive sight amplification systems such as forward looking infrared (FLIR) and night vision goggles, or through active systems using laser and radar technology, such as terrain avoidance/terrain following radar. Active systems provide improved penetration under IMC, and superior range- and azimuth-to-obstacle information for maneuver cues. As yet, displays suitable for NOE maneuvering to avoid obstacles remain to be developed. Cockpit lighting for night operations must also be considered with respect to controls and displays, in order to eliminate the glare from reflective surfaces, and thereby create an environment in which NVG and FLIR systems can be utilized most effectively.

The workload imposed upon pilots during terrain flight is very demanding and can lead to flight limitations. Pilots have indicated that 2 hours of NOE flight time is roughly equivalent to 8 hours of normal flight time. The overwhelming majority of the pilot's time is spent with his head out of the cockpit, and any additional systems, such as obstacle avoidance displays, which increase visual workload will not improve overall terrain flying capability.

Limitations also result from a lack of suitable navigation information, particularly in the NOE environment. Short (1/4-mile) and medium range (2- to 3-mile) terrain information is desired for flight and ground path selection, location and/or bearing to destination, and obstacle identification (such as poles, towers, etc).

Improved capability of the UTTAS will result primarily from technical approaches involving the cargo system, flight control system, visionics and navigation. The U.S. Army has active programs underway in helicopter terrain flying, including training, night operations, visionics and navigation considerations as summarized in References 8, 9, and 10.

The emphasis of this study was to determine how the addition of an external load limits the ability of the UTTAS helicopter to perform its support mission close to the ground. Cargo suspension and handling qualities improvements are defined and analyzed with the objective of restoring as much of the day VFR internal load capability as practical. Visionic system characteristics from existing programs, including those mentioned above, were integrated into the study to establish potential nighttime capability.

This report presents the limitations of the UTTAS helicopter in performing terrain flying with external loads. The limitations are quantified using the results of computer simulations of selected terrain flight maneuvers. In addition, candidate concepts are identified for correcting these limitations and a preliminary system definition of selected cargo system candidates is provided.

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8. AIRCREW PERFORMANCE IN ARMY AVIATION, Proceedings of a Conference that Convened at the U.S. Army Aviation Center, Fort Rucker, Alabama, 27-29 November 1973.

9. STAYING POWER SYMPOSIUM, U. S. Army Aviation Center, Fort Rucker, Alabama, 8-10 July 1975.

10. THE GUIDANCE AND CONTROL OF V/STOL AIRCRAFT AND HELICOPTERS AT NIGHT AND IN POOR VISIBILITY, AGARD Conference Proceedings No. 148, Stuttgart, Germany, 14-16 May 1974.

3.0 LIMITATION ANALYSIS AND CONCEPT EVALUATION

3.1 MANEUVER SIMULATION DESCRIPTION AND AIRCRAFT/LOAD STUDY CONFIGURATIONS

From initial concepts involving the use of helicopters on a mid-intensity battlefield, and early use of the phrase "nap-of-the-earth flight", several definitions have evolved describing the technique of terrain flying. For purposes of this study, the descriptions of terrain flight described below have been utilized. Terrain flying involves flight close to the ground, and utilizes the tactical application of nap-of-the-earth, contour, and low level flight techniques to limit the enemy's capability to acquire, track, and engage the aircraft.

- Nap-of-the-earth flight is as close to the earth's surface as vegetation or obstacles permit, to stay masked below available cover, while generally following the contours of the earth. Airspeed and flight path variations are common to this phase.

- Coutour flight is at a low altitude conforming generally, and in close proximity, to the contours of the earth. It is characterized by varying airspeed and varying altitude along with flight path.

- Low-level flight is conducted at a selected altitude above all obstacles and along a straight path at constant airspeed.

3.1.1 Terrain Flight Maneuvers Analyzed

In defining the terrain flight limitations of the UTTAS helicopter, each segment of the cargo mission was systematically analyzed. A series of maneuvers, as portrayed and grouped in Figure 8, were selected which were thought to best illustrate typical terrain flight requirements. These maneuvers include:

1. Load Acquisition and Deposit – Although not a terrain flying maneuver per se, the load acquisition phase has been considered due to its impact on flight control accuracy requirements and pilot workload. Any workload reduction in flight phases other than terrain flight will undoubtedly provide an improvement in the terrain flying segment where workload demands are high.

2. Forward Dash – Defined as an NOE task, this maneuver reflects the rapid horizontal translation of the helicopter in an area where cover may be lacking. The maneuver consists of an initial hover, a pitch down rotation to accelerate the aircraft, and finally a pitch up to decelerate back to a masked hover position.

3. Lateral Jink – Similar in concept to the forward dash but performed in a sideward direction.

4. Lateral Terrain Avoidance – This maneuver can be associated with either NOE or contour flight. It is projected as a lateral displacement of the aircraft for obstacle avoidance in forward flight by appropriately varying bank angle and heading. The aircraft is effectively flown around the obstacle in this maneuver.

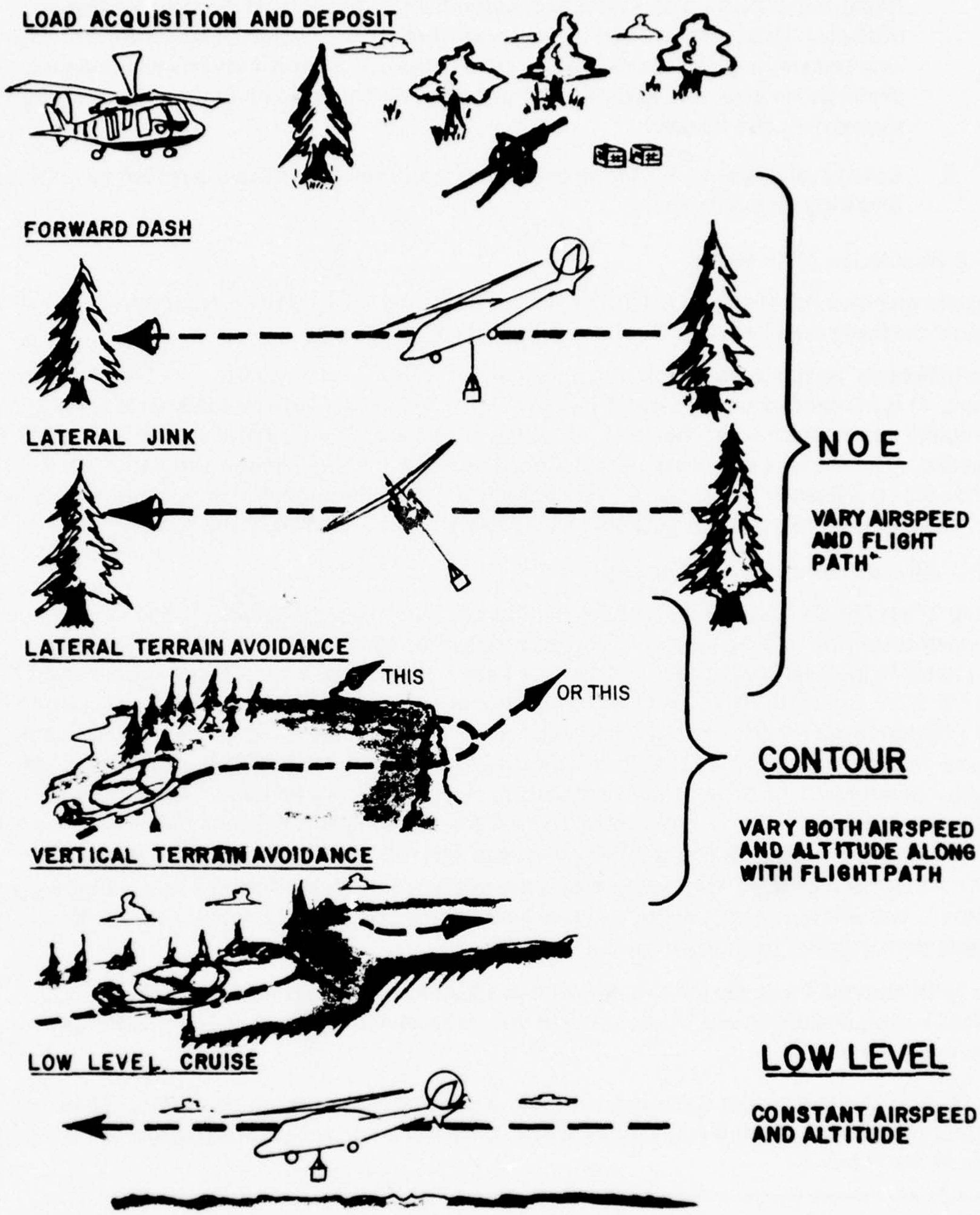

FIGURE 8. TERRAIN FLIGHT MANEUVERS

5. Vertical Terrain Avoidance – Typical of what might be encountered during contour flying and consisting of a vertical displacement of the aircraft in order to clear an obstacle. This maneuver can be achieved through application of cyclic control with airspeed varying significantly, or through collective pitch commands where power demands are great but airspeed changes are minimal. A combination of both techniques may also be used.

6. Low-Level Flight – A cruising condition, performed at constant airspeed and altitude, involving no maneuvering.

3.1.2 Simulation Math Model

A comprehensive full envelope computer simulation of the UTTAS flight characteristics was used to quantitatively assess each of the above terrain flight maneuvers.

The helicopter math model used in this study was previously developed for the UH-61A design effort. It is a total force and moment model of the coupled aircraft and external load dynamics. Complete representations of the rotor, airframe, mechanical flight control system and AFCS are included. The analysis is presently programmed as an all digital computer simulation on the Xerox Sigma 9 System and is capable of both piloted and non-piloted modes. Analytical pilot models were used to execute the terrain flying maneuvers performed in the study.

3.1.3 *Aircraft and Load Configurations*

Table 2 lists the UTTAS internal and external aircraft load configurations studied, and each is grouped according to gross weight. Two gross weight categories were selected for evaluation. The baseline internal-loaded configurations represent the 15,080-pound design gross weight of the UH-61A, and a 19,500-pound weight which is at or near the maximum weight permissable for a 500-foot-per-minute vertical climb capability. For the external-load cases, an A-22 ammunition bag and a 105mm M101A1 howitzer piggybacked with an A-22 bag were selected as being representative of the missions described in Reference 1 for an assault support helicopter operating in a high-threat environment. The A-22 is currently the standard forward area resupply container for tactical units and should continue in this role for the foreseeable future. The M101A1, version of the 105mm howitzer is the primary U.S. Army forward area artillery support weapon, and will represent a major external load for the UTTAS helicopter. The loads and rigging were selected from References 11 and 12.

For both external loads the aircraft weight was adjusted so that the total aircraft and load weight was equivalent to one of the internal loaded baselines,as shown in Table 2, for direct data comparison.

In addition to the standard suspension lengths, shortened restraints are also listed. These slings represent a new approach but utilize standard Army slings currently available, and are discussed later in Section 3.3.1.

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11. Technical Manual 55-450-11, AIR TRANSPORT OF SUPPLIES AND EQUIPMENT: HELICOPTER EXTERNAL LOADS RIGGED WITH AIR DELIVERY EQUIPMENT, Headquarters, Department of the Army, Washington, D.C., 21 June 1968.

12. Technical Manual 55-450-12, AIR TRANSPORT OF SUPPLIES AND EQUIPMENT: HELICOPTER EXTERNAL LOADS FOR SLING, NYLON AND CHAIN, MULTIPLE LEG (15,000-POUND CAPACITY), Headquarters, Department of the Army, Washington, D.C., 3 June 1969.

TABLE 2. UTTAS HELICOPTER TERRAIN FLIGHT SIMULATION CONFIGURATIONS

CONFIGURATIONS	AIRCRAFT GROSS WEIGHT (LB)	EXTERNAL LOAD (LB)	SUSPENSION CONFIGURATION	SLING LENGTH
BASELINE INTERNAL (DESIGN GROSS WEIGHT)	15,080	–	–	–
• A-22 AMMO BAG	13,205 (1)	1,875	SINGLE POINT	STANDARD (18.5 FT) (2) SHORT (3.5 FT) (2)
BASELINE INTERNAL (500 FPM VERT R/C)	19,500	–	–	–
• 105MM – M101A1 HOWITZER AND PIGGYBACK A-22 AMMO BAG	12,845 (1)	4,780 GUN 1,875 A-22 6,655 TOTAL	SINGLE POINT	STANDARD (15/14 FT) SHORT (8/5 FT)

NOTES: (1) A/C WEIGHT WITHOUT EXTERNAL LOAD

(2) INCLUDES NYLON SLING/CHAIN LEG COMBINATION

3.1.4 UH-61A Load Sway Limits

In order to establish load sway angle limits for the UTTAS aircraft, while carrying the A-22 bag and 105mm howitzer (with piggyback A-22 pack) external loads used in the terrain flying simulation study, three types of restraining criteria were considered. These included limitations imposed by:

- Aircraft local structure or hook design loads for various load sway conditions
- Hook impingement on internal (built in) sway angle stops, or on aircraft structure
- Load or load suspension interference with aircraft structure such as landing gear, etc.

Each category of sway limitation was looked at in depth, to determine the amount of load pendular sway motion permitted in the longitudinal and lateral axes prior to reaching a limit. The hook configuration utilized in the study was the UH-61A installation flown during the UTTAS Government Competitive Test (GCT) program.

In Table 3 which follows, load and hook configurations are annotated first, followed by the type of sling, direction of sway, magnitude of sway limit, and an indication of what parameter caused the limit to occur. Limiting criteria applied in the simulation maneuver study were taken from this table.

3.2 TERRAIN FLYING MANEUVER ANALYSIS

3.2.1 Longitudinal Dash

The longitudinal dash is depicted on Figure 9 with a summary of the general limitations associated with the maneuver. The maneuver consists of an initial hover, a pitch down rotation to accelerate the aircraft, followed by a pitch up to decelerate back to a hover.

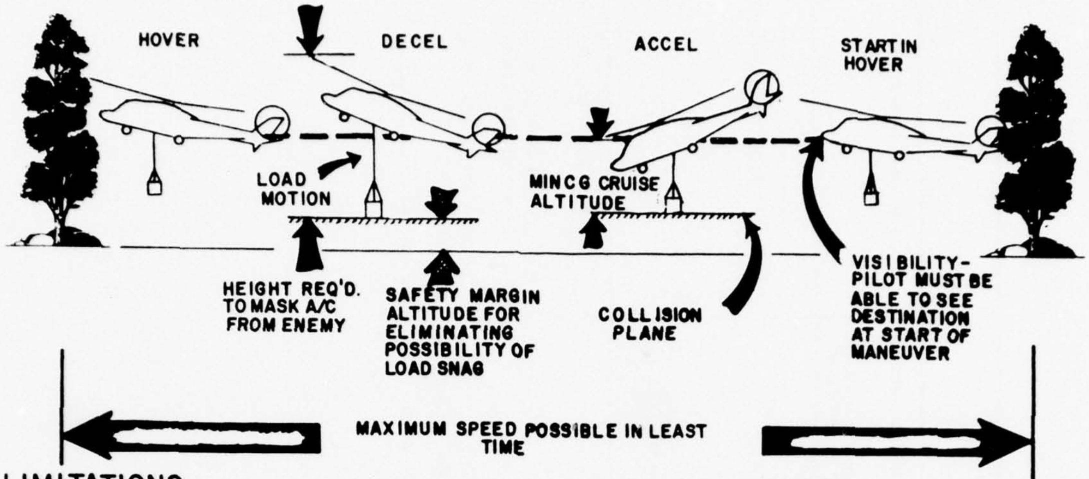
Basically, the restrictions which result with external loads on conventional suspensions are severe and increase the time required to transverse a given distance. Specifically, load dynamic characteristics associated with poor inherent damping levels produce either large angular excursions of the load (proportional to maneuver severity) or result in a tendency for PIO during night/IMC conditions. This PIO tendency has even been encountered in VFR operations, and can lead to load/airframe collisions, or requirements that the pilot jettison the cargo to preclude loss of aircraft control.

Pilot workload levels experienced during mild maneuvering conditions are normally higher when operations are conducted with external cargo. Constant awareness of the load and its motion are ever present, while the desire for maximum masking during terrain flying, and visibility during night/IMC conditions, require even higher demands on the pilot.

Minimizing exposure of the aircraft to the enemy threat is obviously what necessitates terrain flying. Masking considerations, indicative of the requirements to hide the aircraft behind appropriate cover, increase above the internal loaded configuration, reflecting the additional height required for sling length and load, maneuver level, and safety margins to prevent load

TABLE 3. UH-61A (UTTAS) LOAD SWAY ANGLE LIMITATIONS

LOAD/SUSPENSION CONFIGURATION	SLING LENGTH		LONGITUDINAL SWAY ANGLE LIMIT		LATERAL SWAY ANGLE LIMIT		LIMITING PARAMETER
	STD SLING	SHORT SLING	STD SLING	SHORT SLING	STD SLING	SHORT SLING	
A-22 AMMUNITION BAG LOADED WITH 105 MM HOWITZER SHELLS ~1875 LB~	18.5-FT SLING/ CHAIN LEG	3.5-FT CHAIN	FWD SWAY + 30° AFT SWAY - 30°	FWD SWAY + 30° AFT SWAY - 30°	BOTH DIR ± 30°	BOTH DIR ± 30°	AIRCRAFT/HOOK STRUCTURAL DESIGN LOADS
105 MM M101A1 HOWITZER AND A-22 "PIGGYBACK" PACK ~6655 LB~	14/15 FT	7/8 FT	FWD SWAY + 30° AFT SWAY - 30°	FWD SWAY + 26° AFT SWAY - 27°	BOTH DIR ± 30°	BOTH DIR ± 30°	AIRCRAFT/HOOK STRUCTURAL DESIGN LOADS BARREL HITS ANTI COLLISION LIGHT AFT SLING HITS MAIN GEAR AIRCRAFT/HOOK STRUCTURAL DESIGN LOADS



LIMITATIONS:

MANEUVERABILITY

- AIRCRAFT LOW-SPEED PERFORMANCE
- LOAD MOTION (SEVERE RESTRICTION)
  - POORLY DAMPED LONGITUDINAL SWAY
  - LOAD TO FUSELAGE STRIKES OR STRUCTURAL LIMITS
- PILOT-INDUCED OSCILLATIONS (PIO)
  - POTENTIAL HIGH IN NIGHT/IMC
  - ALSO EXPERIENCED IN VFR OPERATIONS

WORKLOAD (VERY HIGH)

- HANDLING QUALITIES
- LOAD MOTION
- VISIBILITY

MASKING (OBSTACLE HEIGHT REQUIRED TO HIDE AIRCRAFT)

- AIRCRAFT AND LOAD HEIGHT
- MANEUVER SEVERITY (LARGE ALTITUDE CHANGES)
- SAFETY MARGIN TO PREVENT LOAD SNAGS

SPEED/TIME

- AIRCRAFT MANEUVERABILITY
- DASH LENGTH
- VISIBILITY - OBSTACLE AVOIDANCE

NAVIGATION/COMMUNICATIONS

- GENERALLY NOT COMPATIBLE WITH NOE/CONTOUR AND HIGH THREAT
  - SYSTEMS REQUIRE LINE OF SIGHT
  - JAMMABLE, ETC.

(NOT EMPHASIZED IN THIS STUDY)

FIGURE 9. FORWARD DASH MANEUVER

snags on obstacles. As such, utilization of shortened suspensions and load snubbing concepts can offer a means of reducing the penalty incurred by external loads.

In addition to masking, the amount of time required for translation reflects the potential degree of exposure to the enemy. Here again, maneuver limits established from load motions or visual capability minimize dash speeds and lengths while increasing the time required for mission completion.

Longitudinal acceleration/deceleration (dash) maneuvers from a hovering condition were performed as illustrated by the commanded maneuver profiles in Figure 10, for mean longitudinal acceleration/deceleration levels of 0.087, 0.174, 0.25, 0.34 g. These values correspond to nominal pitch attitude changes of ±5, ±10, ±15, ±20 degrees, respectively. Varying dash lengths were obtained for each maneuver by increasing the period over which the attitude change was held.

3.2.1.1 Internal Baseline (15,080 Pound) and A-22 Ammo Bag Results

Figure 10 presents the resultant longitudinal distances traversed for the internally loaded baseline configuration as functions of total maneuver time, and commanded pitch attitude change. Aircraft safety and masking considerations are presented in Figure 11 as minimum clearance heights required for the maneuver.

Height (A), reflecting aircraft altitude, is defined as the distance from the center of gravity to the lowest point on the aircraft where collision plane contact would occur. Height (B), indicative of the masking requirement, is defined by the distance from the collision plane to the highest point on the aircraft. This distance is a direct function of maneuver severity, with the tip of the rotor disk plane protruding further and further above the collision plane as greater pitch attitude excursions are used. Both heights (A) and (B) do not, however, include a safety margin which would be required to eliminate any possibility of load snags or contact with undetected obstacles. No attempt has been made in this study to determine what degree of safety margin is required, as it is a function of pilot training level, terrain familiarity, type of load, etc.

The time to translate over a specific dash length obviously decreases with increasing acceleration/deceleration levels. Referring to Figure 10, maneuvering 800 feet with a nominal acceleration/deceleration of 0.087 g ($5^{o}\Delta\theta$) would take approximately 37.0 seconds, whereas increasing the level to 0.34 g ($20^{o}\Delta\theta$) would require about 19 seconds. To accomplish this translation in a shorter period of time does, however, result in an increase of 16.5 feet in masking height (Figure 11). Plotted on the bottom of Figure 11 are the maximum speeds achieved during the acceleration phase. Crossplots of these velocities at 30 and 60 knots appear on Figure 10.

The resultant dash lengths associated with a particular maneuver time and command pitch attitude do not change with addition of the A-22 ammunition bag, as shown in Figure 12, since the acceleration is directly proportional to $\Delta\theta$. The minor changes observed are a result of the pilot model fidelity only. However, limitations due to load dynamics result in severe reductions in the maximum acceleration/deceleration levels permissible. The limiting factors stem from two sources which are:

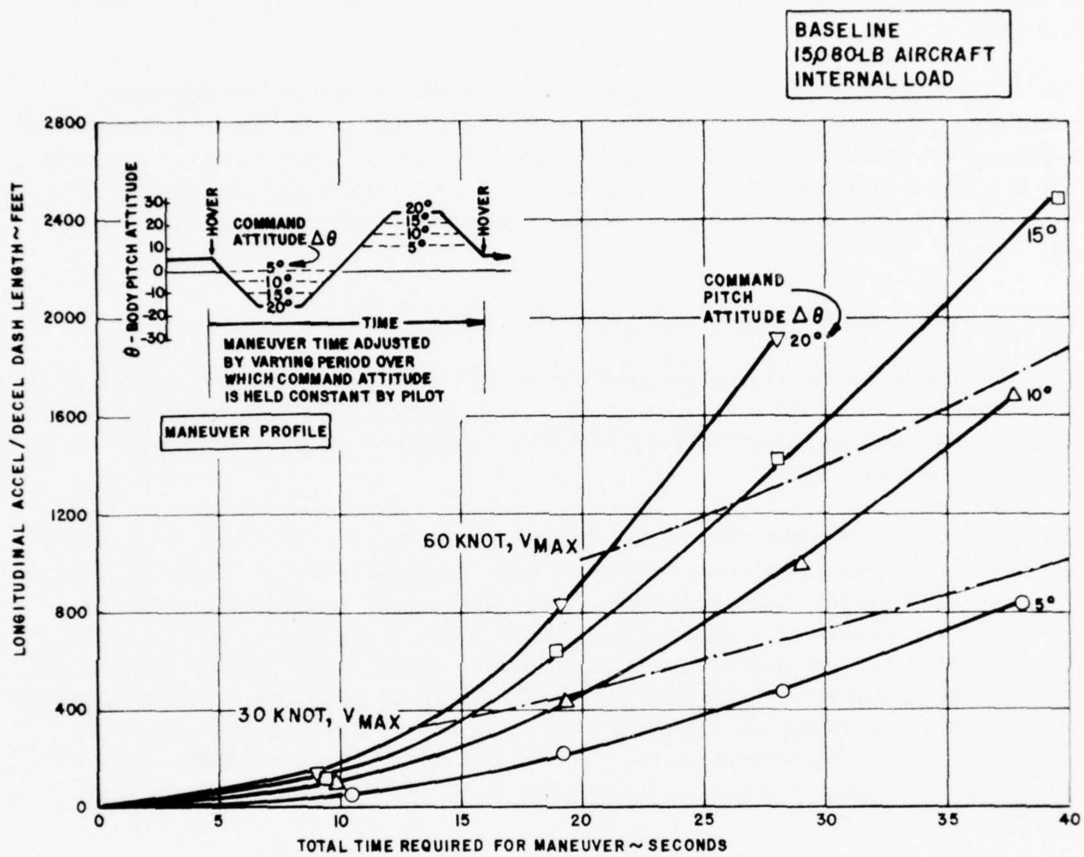


FIGURE 10. UTTAS DASH LENGTH/TIME - INTERNAL LOAD BASELINE (15,080 LB)

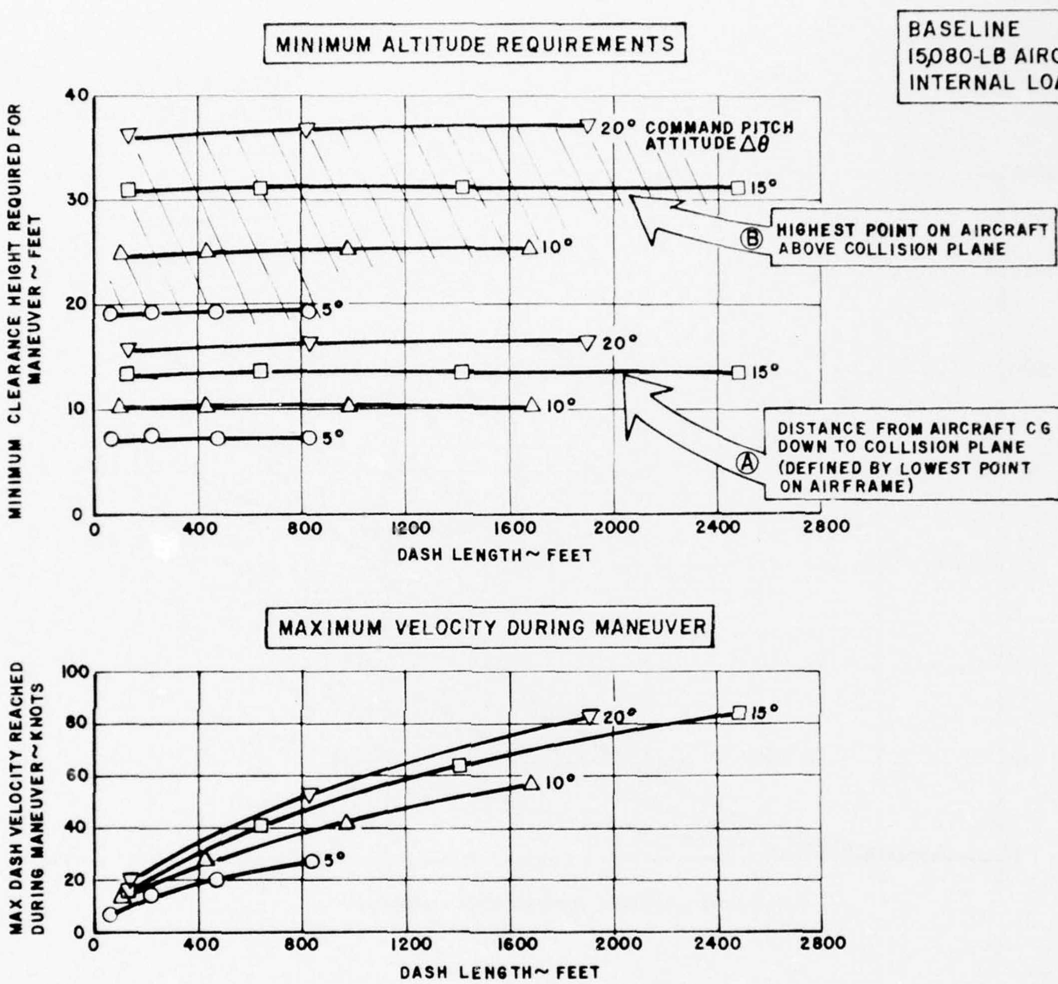


FIGURE 11. BASELINE HEIGHT REQUIREMENTS AND PEAK VELOCITIES FOR DASH MANEUVER

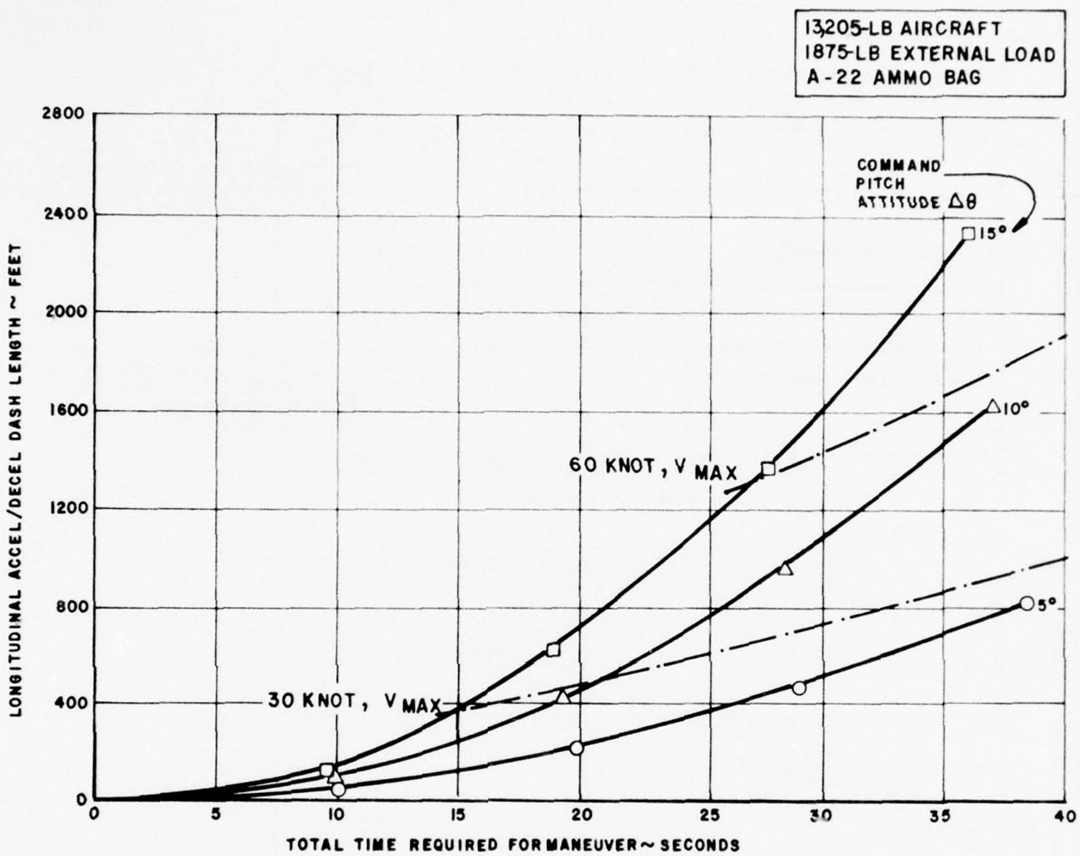


FIGURE 12. DASH LENGTH/TIME WITH EXTERNAL LOAD

- Increasing sway motion with maneuver severity

- PIO susceptibility from lightly damped load oscillations.

The peak sway motions (forward and aft) are plotted in Figure 13 for sling lengths of 18.5 feet (long) and 3.5 feet (short), both on single hook suspensions. The hook sway limits from Section 3.1.4 are superimposed. Note that the sway limits were not included in the model and the data shown are the angles through which the load would traverse if no load or hook interference occurred. Translating the sway angle limits into maximum permissible body attitudes or acceleration/deceleration levels reveals that the maneuverability is roughly cut in half, being limited to about 11 degrees for the long slings and 7.5 degrees for the short. These limits are reflected on the dash length-vs-time plot, Figure 14.

Masking height requirements with external loads (under the same levels of maneuverability) are of necessity increased over the baseline configuration as shown in Figure 15. For the long sling suspension, the required increase is nominally 25 feet for both masking and clearance heights. Adopting a short sling suspension reduces this increase to approximately 12 feet. When compared at their respective maneuverability limits, the required masking height increase with the external load is lower due to the reduced pitch attitude. The reduction in aircraft maneuverability and increase in masking requirements with the external load reduces the aircraft survivability on a hostile battlefield.

In addition to the restrictions imposed by the sway limits, limitations may also occur as a result of pilot induced oscillations due to load motion, particularly at night or under reduced visibility conditions. The load motion creates longitudinal and lateral accelerations in the helicopter, producing a confusing motion cue pattern for the pilot. This can result in pilot control inputs which excite rather than damp out the load motion.

Airframe longitudinal accelerations resulting from the dash maneuver are presented in Figure 16. A maximum of 0.05 g is associated with the onset of pilot induced oscillation (PIO) in IFR or night conditions based on the flight test results of Reference 4. For the A-22 container, these reduced visibility PIO boundaries fall in the same region as the sway limits. The severity of this characteristic grows substantially as the load-to-aircraft weight ratio increases, as shown below for the 105mm howitzer.

3.2.1.2 Internal Baseline (19,500 Pounds) and 105mm Howitzer Results

The dash length-vs-time required data for this configuration is shown in Figure 17 as a function of pitch attitude. The basic data is similar to that shown in Figure 10 for the internal load at design gross weight (15,080 pounds), as acceleration levels are dependent only on attitude changes.

The limitations imposed on the dash maneuver with the A-22 cargo bag piggy-backed on a 105mm M101A1 howitzer are summarized in Figure 18. The reduced maneuvering envelope due to load sway is similar to that obtained for the A-22 bag alone; however, the restrictions due to PIO susceptibility are more severe due to increased load-to-aircraft weight ratio. Load sway and PIO susceptability data is shown in Figure 19.

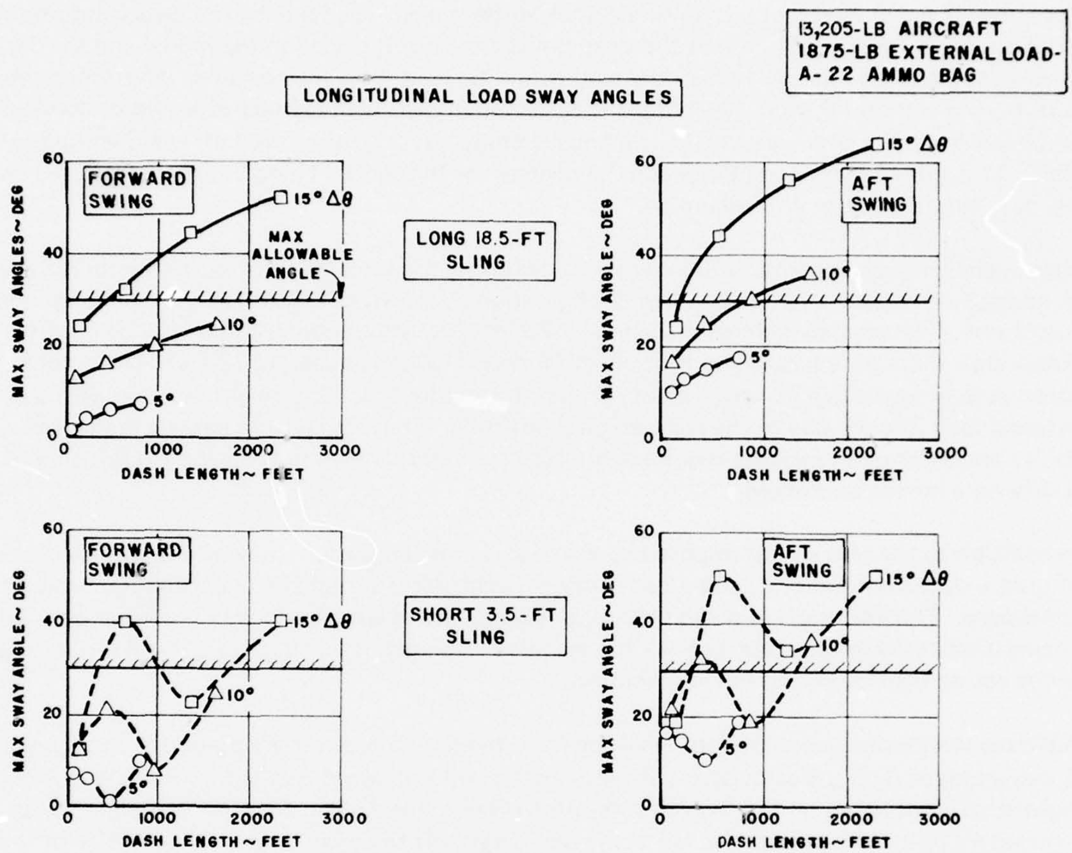


FIGURE 13. PEAK SLING LOAD SWAY ANGLES DURING DASH MANEUVER (A-22 AMMO BAG)

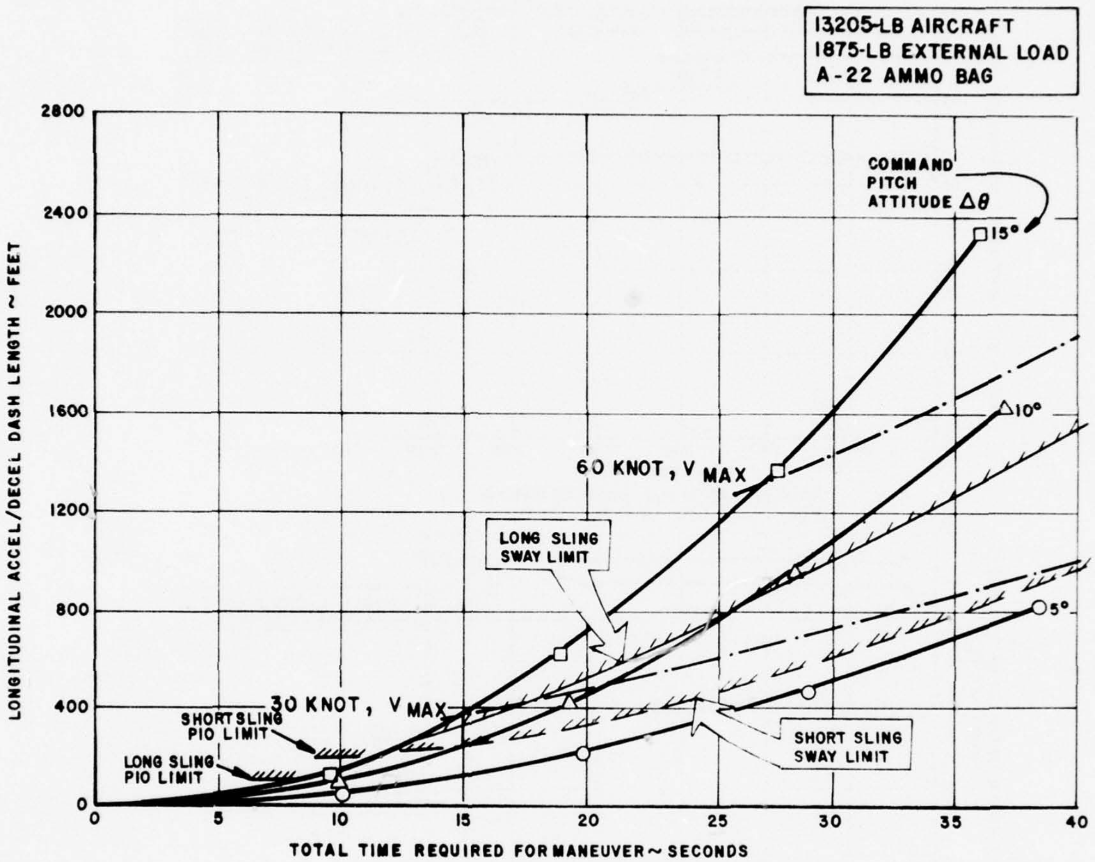


FIGURE 14. DASH MANEUVER LIMITATION IMPOSED BY A-22 AMMO BAG

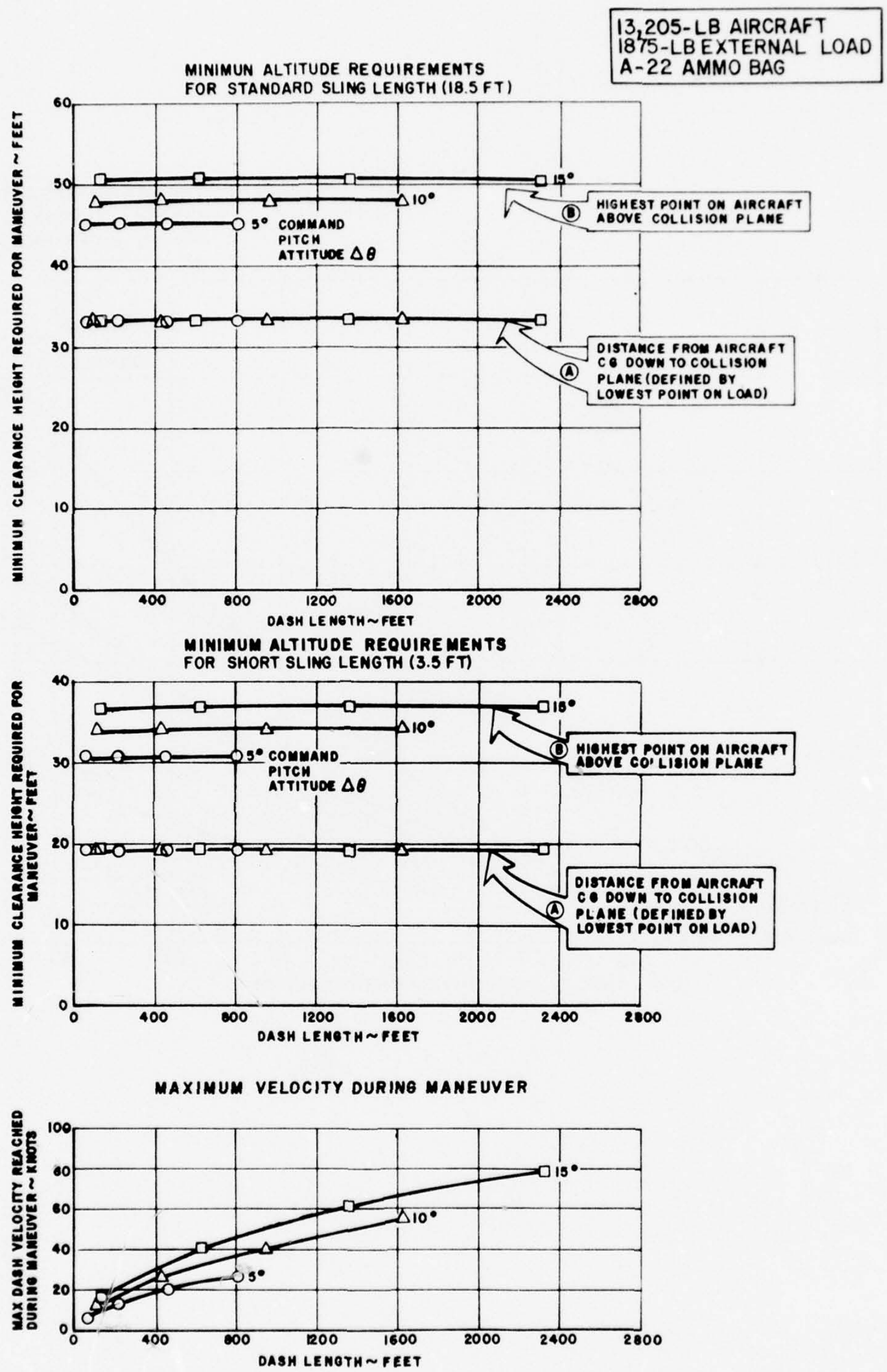
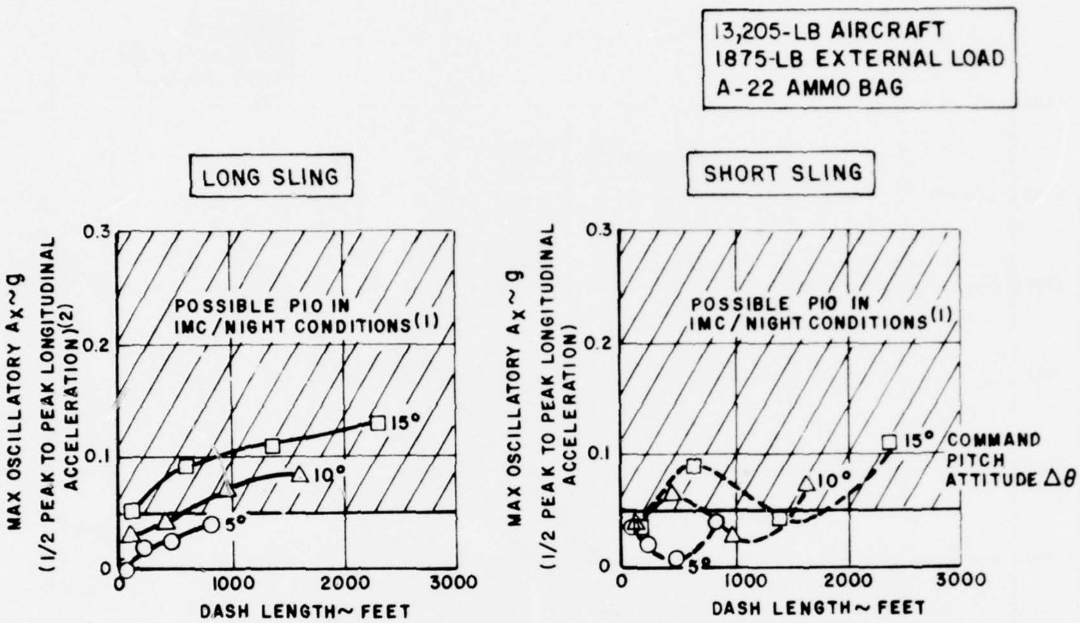


FIGURE 15. HEIGHT REQUIREMENTS AND PEAK VELOCITIES FOR DASH MANEUVERS WITH EXTERNAL LOAD (A-22 AMMO BAG)



NOTES

1. CRITERIA FOR PIO BASED ON A_X = 0.05 g FROM AAELSS I FLIGHT TEST RESULTS WITH PILOT UNDER HOOD
2. 1/2 PEAK TO PEAK A_X RESULTING FROM LOAD SWAY ONLY

FIGURE 16. PIO SUSCEPTIBILITY DURING DASH MANEUVER WITH A-22 AMMO BAG

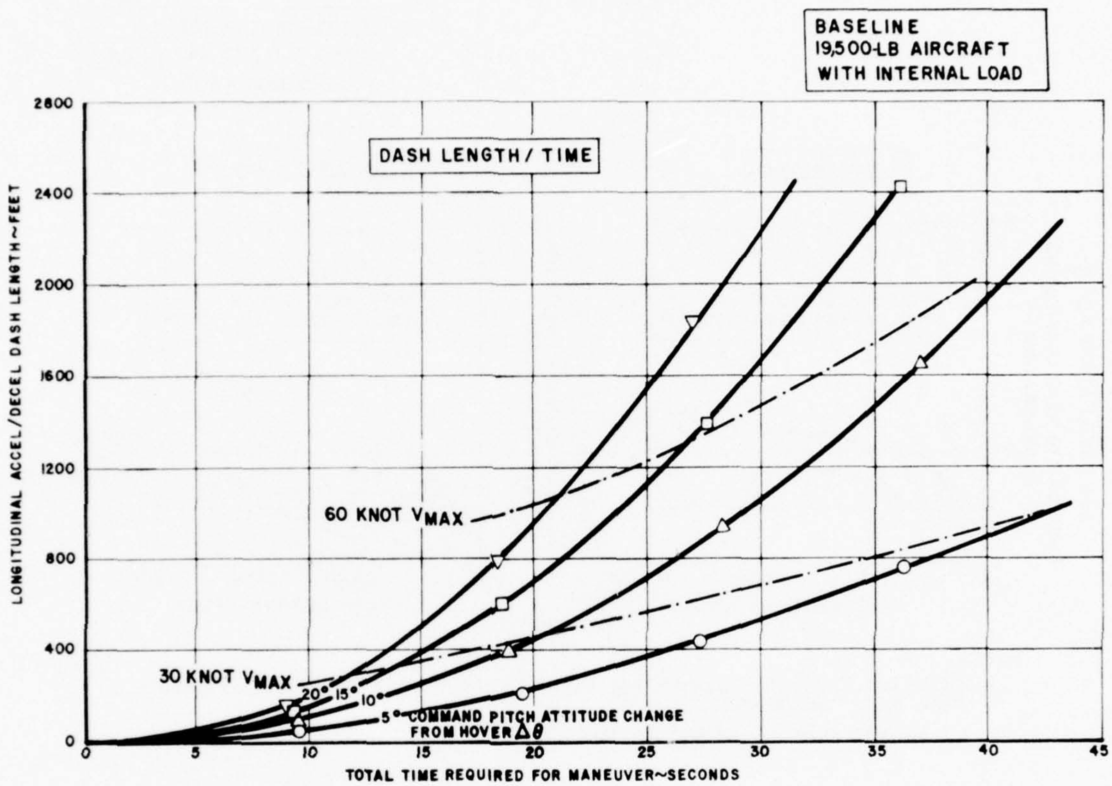


FIGURE 17. UTTAS DASH LENGTH/TIME-INTERNAL LOAD BASELINE (19,500 LB)

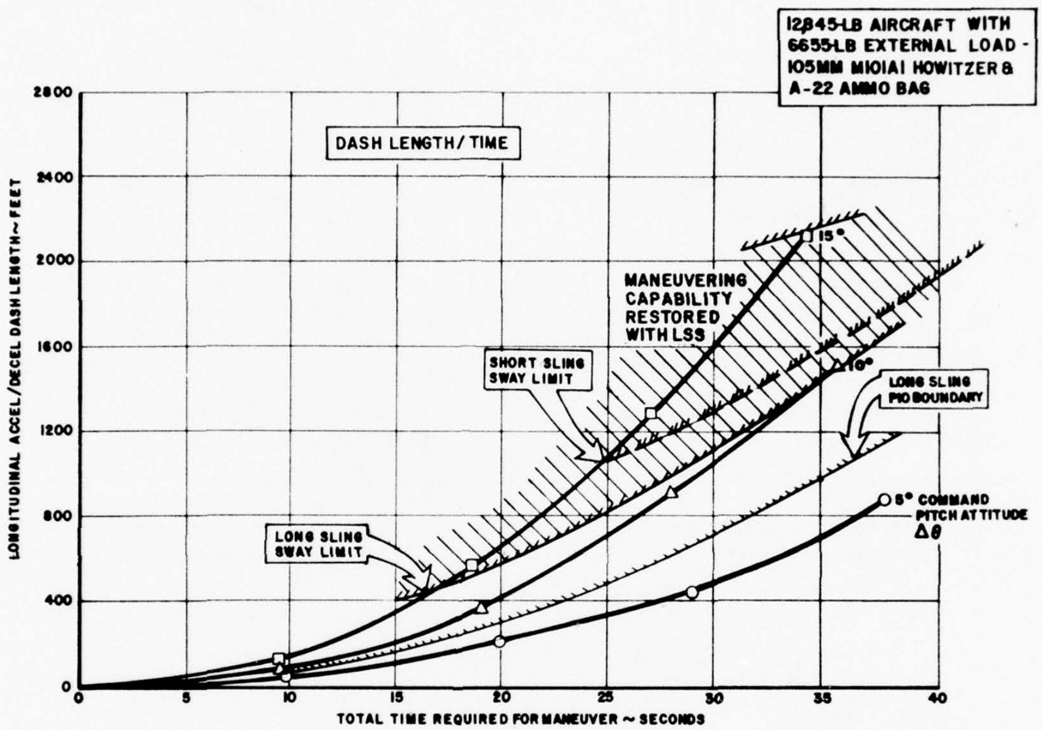


FIGURE 18. DASH MANEUVER RESTRICTIONS WITH EXTERNAL LOAD (105 MM HOWITZER AND A-22 AMMO BAG)

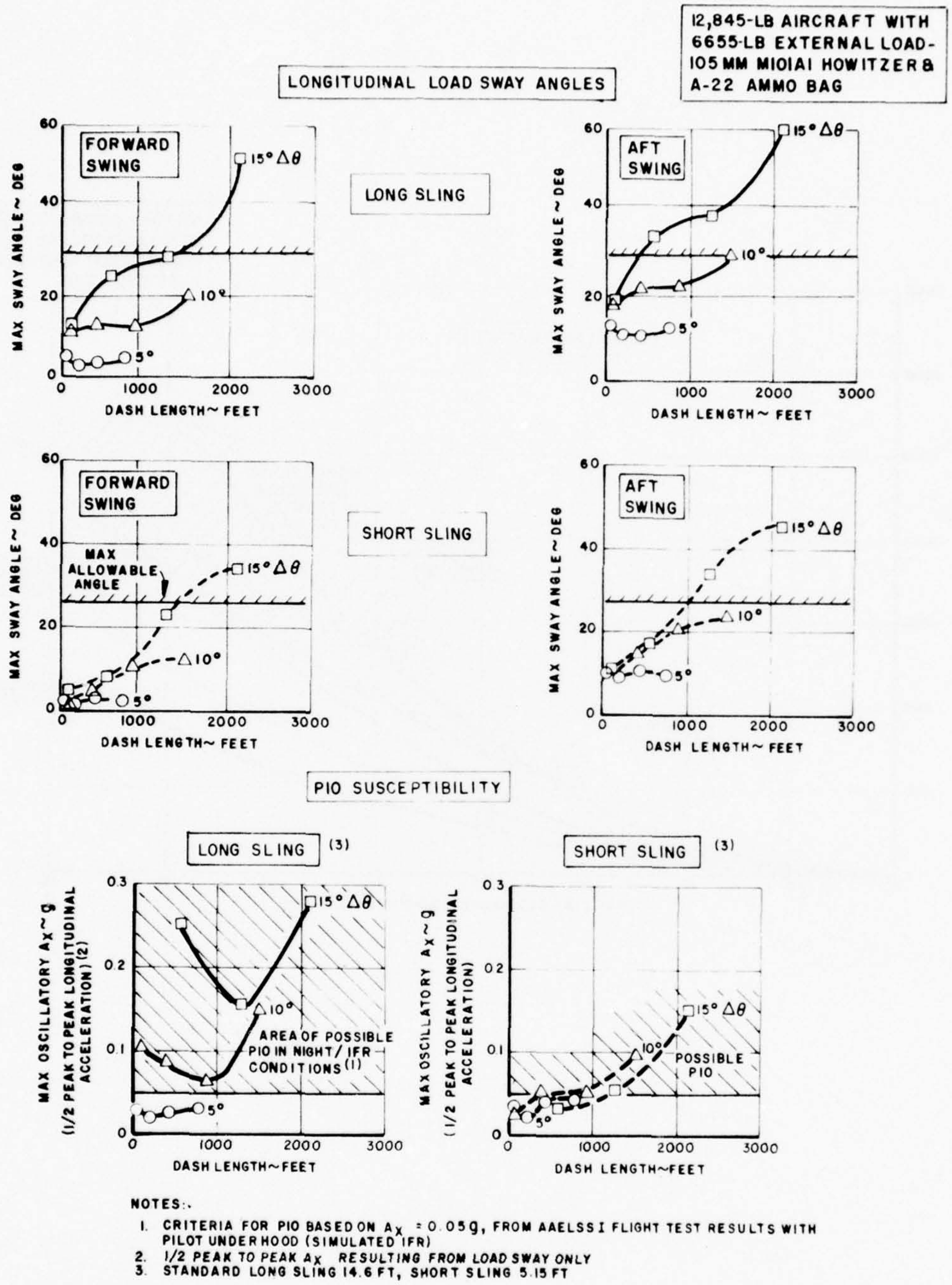


FIGURE 19. PEAK SLING LOAD SWAY ANGLES AND PIO SUSCEPTIBILITY DURING DASH MANEUVERS (105 MM HOWITZER AND A-22 AMMO BAG

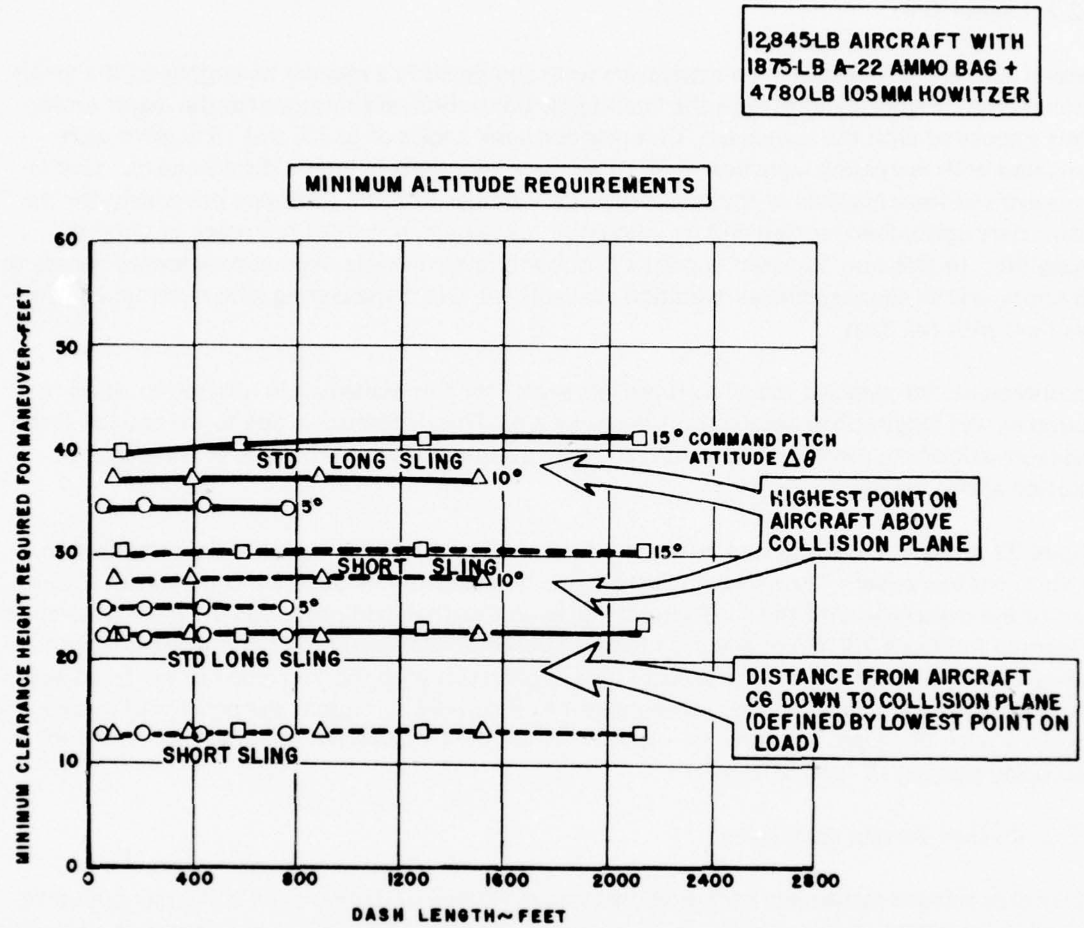


FIGURE 20. HEIGHT REQUIREMENTS FOR DASH MANEUVER WITH EXTERNAL LOAD (105MM HOWITZER/A-22 AMMO BAG)

Minimum clearance height requirements for this external load configuration are plotted in Figure 20. An increase of 15 feet over the internal load baseline is indicated for the standard long sling, while increases of 5 feet are required for the short version.

3.2.2 Lateral Jink

Lateral acceleration/deceleration maneuvers were simulated in a manner analogous to the longitudinal dash. Figure 21 illustrates the lateral jink translation and summarizes the major limitations associated with the maneuver. Commanded bank angles of 5, 10, and 15 degrees were evaluated with increasing maneuver time to produce variations in lateral displacement. Limitations evolved from analysis of these maneuvers are similar to those discussed previously for the dash. Here again, load motion and its inherently low damping restrict full usage of aircraft capability. In this case, however, a pilot's handbook limit restricts maximum sideward speeds to 35 knots, and so the percentage reduction available for safe maneuvering with external loads is less than with the dash.

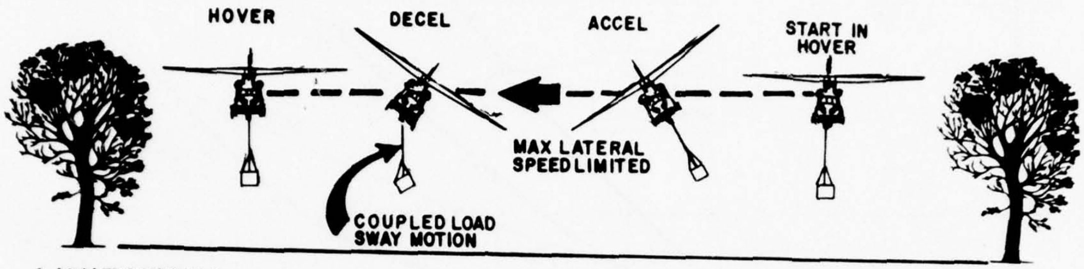
Requirements for masking the aircraft are less severe for this maneuver in relation to those required by the longitudinal acceleration/deceleration. This difference is due to the smaller linear displacement of the rotor resulting from angular rotation about the roll axis as compared to rotation about the pitch axis.

Figure 22 presents the computed lateral displacements as a function of total time required to execute the maneuver. The sideward flight velocity restriction of 35 knots is indicated. Execution of the maneuver with the A-22 ammo bag as an external load produced the peak sway angles presented in Figure 23. Comparison of load motion with standard (long) and short suspensions indicates that slightly larger excursions in load angle result with the shortened sling. Load sway limits are shown which have been translated on to Figure 24 to present the permissible maneuver envelope with this load, and reflect an approximate 15- to 30-percent reduction in maneuver capability because of load motion.

3.2.3 Vertical Terrain Avoidance

Vertical avoidance maneuvers were executed and evaluated utilizing a pure collective pullup to obtain the necessary flight profile. In this method airspeed is kept fairly constant with negligible changes occurring in fuselage attitude. Other flight path control techniques are of course possible, using either a pure cyclic control pullup (where airspeed varies appreciably, and associated downrange distances are less) or combinations of collective and cyclic control application. The advantages of each technique are dependent on initial airspeed and obstacle clearance height. For large vertical displacements (greater than 300 feet) and low airspeeds (less than 90 knots) a collective pullup represents the only viable means for obstacle avoidance.

The vertical avoidance maneuver is shown pictorially in Figure 25. The general limitations caused by the external load are alos summarized in the figure. These limits primarily affect the maneuverability and masking levels of the basic aircraft. Maximum airspeeds from which these maneuvers can be initiated are reduced as a result of transient load sway angles and probable PIO occurrence during reduced visibility flight conditions.



LIMITATIONS:

MANEUVERABILITY

- AIRCRAFT LOW SPEED PERFORMANCE
- LOAD MOTION
  - POORLY DAMPED ROLL-YAW MODE
  - LATERAL PIO POTENTIAL

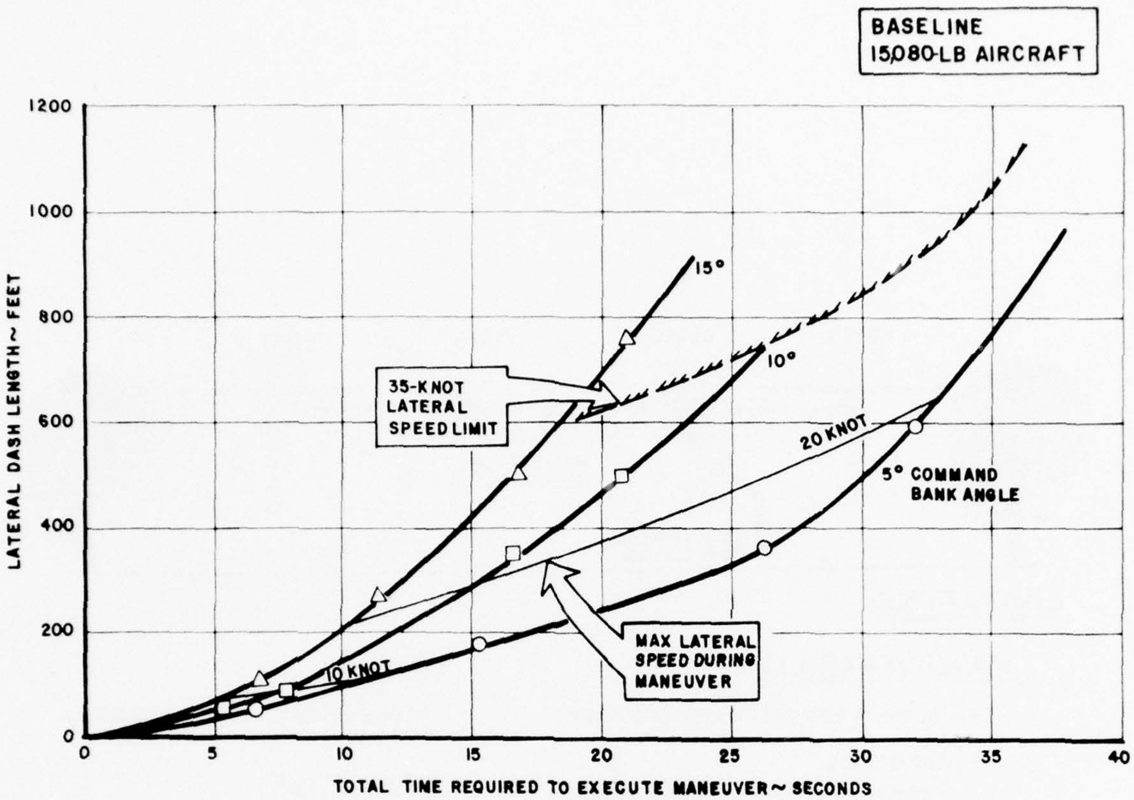
MASKING

- LESS SEVERE THAN LONGITUDINAL DASH

SPEED/TIME

- 35-KNOT SIDEWARD FLIGHT ENVELOPE RESTRICTION

FIGURE 21. LATERAL JINK MANEUVER



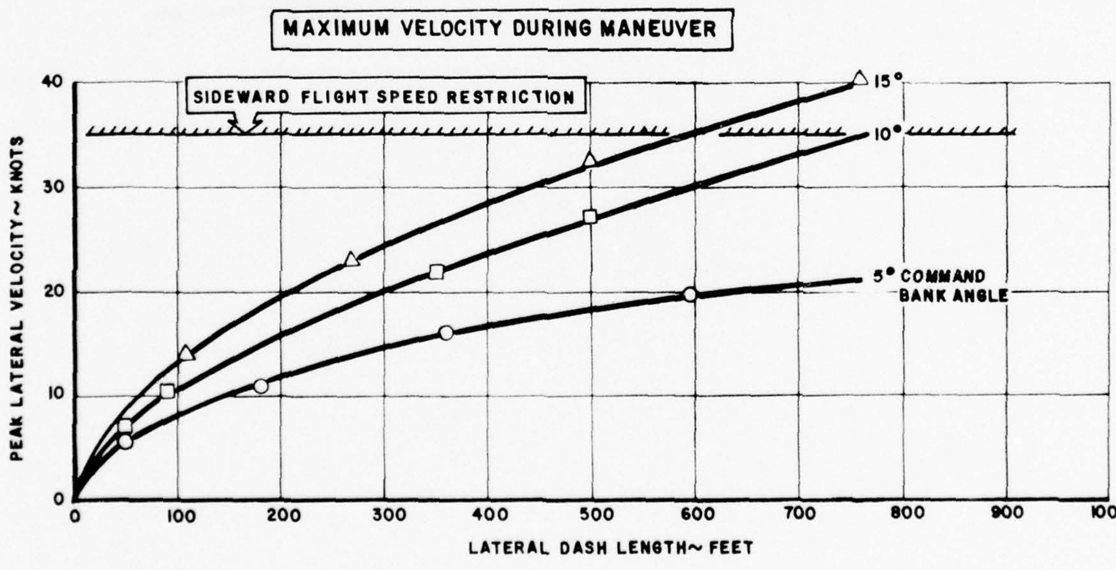


FIGURE 22. LATERAL JINK LENGTH/TIME - INTERNAL LOAD BASELINE (15,080 LB)

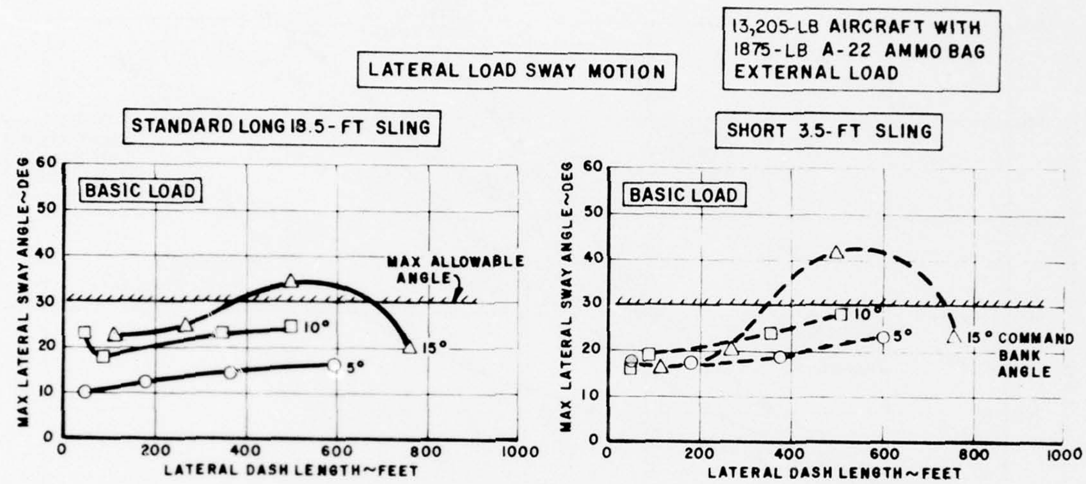


FIGURE 23. PEAK SLING LOAD SWAY ANGLES DURING LATERAL JINK MANEUVER, A-22 AMMO BAG

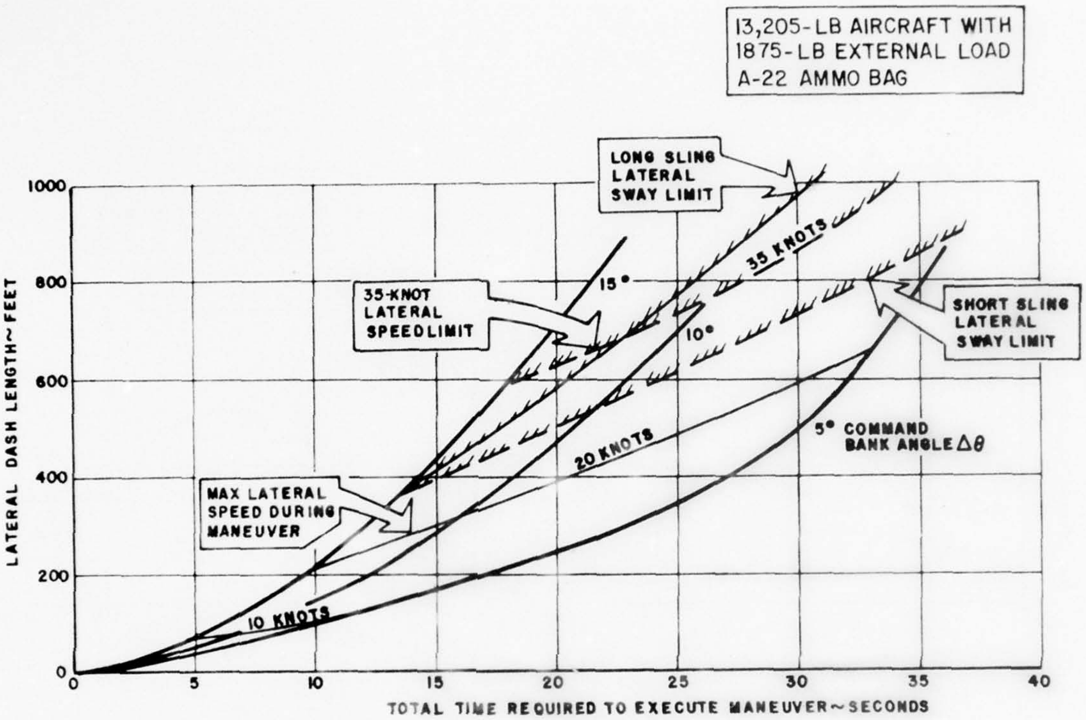
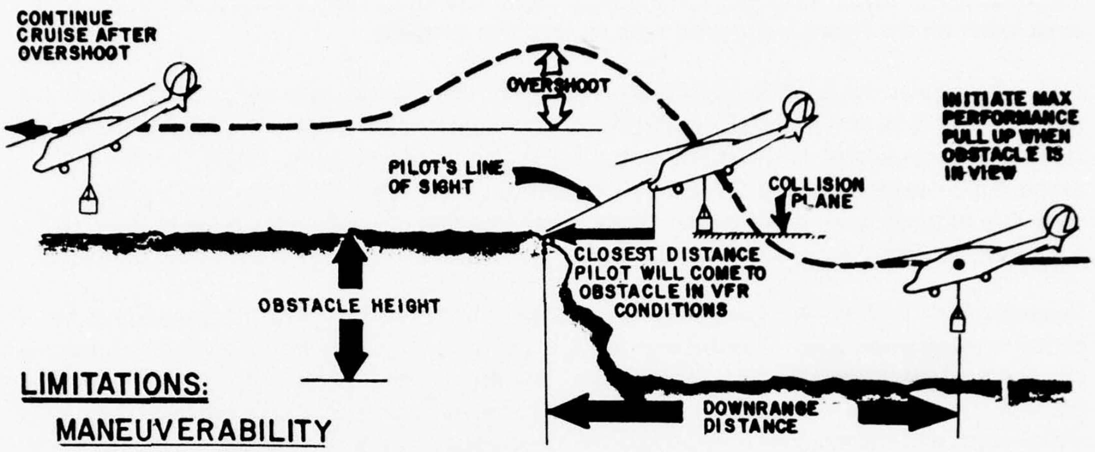


FIGURE 24. LATERAL JINK MANEUVER LIMITATIONS WITH A-22 AMMO BAG



LIMITATIONS:

MANEUVERABILITY

- AIRCRAFT PERFORMANCE WITH EXTERNAL LOAD
  - LOAD DRAG/RATE OF CLIMB OF THE AIRCRAFT
- DOWNRANGE DISTANCE TO CLEAR OBSTACLE
  - VISIBILITY INFLUENCE
    - VFR
    - NIGHT/IMC
- LOAD MOTION
  - PIO
  - SPEED RESTRICTION

WORKLOAD

- HIGH, BUT LESS SEVERE THAN DASH AND JINK

MASKING

- OVERSHOOT ADDS TO AIRCRAFT-LOAD MASKING REQUIREMENTS
- SAFETY MARGIN ALTITUDE REQ'MTS INCREASE WITH SPEED
  - LOAD SNAG

SPEED/TIME

- LOAD STABILITY
- VISIBILITY
- OBSTACLE SIZE

FIGURE 25. VERTICAL TERRAIN AVOIDANCE MANEUVER

3.2.3.1 Vertical Terrain Avoidance – Internal Load Baseline (19,500 Pounds)

Each collective pullup run utilized maximum performance inputs which were limited by engine torque levels at most airspeeds. Figure 26 presents the downrange maneuver distance (referenced to aircraft cg) required to clear obstacle heights ranging from 50 to 1,000 feet for the internally loaded aircraft. Initial airspeeds varying from 30 to 120 knots were investigated. Also shown as an insert on the figure is the total time to clear the obstacle.

Figure 27 defines the minimum clearance heights for the baseline collective pullup. These distances, referred to as (A) and (B) in the sketch, are independent of obstacle height, since the attitude changes which occurred during the maneuvers were negligible. Slight changes with airspeed are noted, reflecting the differences in initial trim pitch attitude. Again, a safety margin in altitude is required to provide adequate clearance throughout the maneuver. The magnitude of this margin would be dependent upon pilot proficiency and terrain familiarity.

Parameters (C) and (D) in Figure 27 define the additional downrange distances required for VFR collision plane avoidance. This distance reflects the minimum distance through which the pilot can maintain visual contact with the obstacle. At this distance he will normally make sure he is above the obstacle. Clearance (C) accounts for the distance from the obstacle to the nose of the aircraft, while clearance (D) accounts for the distance to the cg position. These distances must be included in downrange distance requirements.

3.2.3.2 Vertical Terrain Avoidance With External Loads

The vertical pullup maneuvers were repeated with the 105mm howitzer and piggybacked A-22 ammo bag with the downrange distance requirements presented in Figure 28. Load sway angle data resulting from the maneuvers are shown in Figure 29 together with the associated limits. As noted, sway motion produced by this load does not restrict the capability of the UTTAS helicopter. Also the levels of longitudinal accelerations, though not presented here, were sufficiently low that the likelihood of PIO is remote. This was not the case during the longitudinal dash.

Minimum altitude requirements and the VFR collision plane avoidance distances are presented in Figure 30. Compared to baseline information in Figure 27, nominal height increases of 8 feet and 17 feet are required for the short and long slings, respectively. VFR collision plane avoidance distances have increased as much as 16 feet for the short slings, and 28 feet for the standard length suspension.

3.2.3.3 Vertical Terrain Avoidance Internal Load (15,080 Pounds)

Figure 31 summarizes the results of maneuvers conducted with an internal load at design gross weight. For this configuration downrange requirements are approximately 45 percent lower than the distances obtained at higher weight (Figure 26). This trend is attributed to lower initial levels of power required at the lighter weight, and associated higher rates of climb capability.

Because it was anticipated that no limitations would be produced with the A-22 container, an evaluation with this configuration was not conducted.

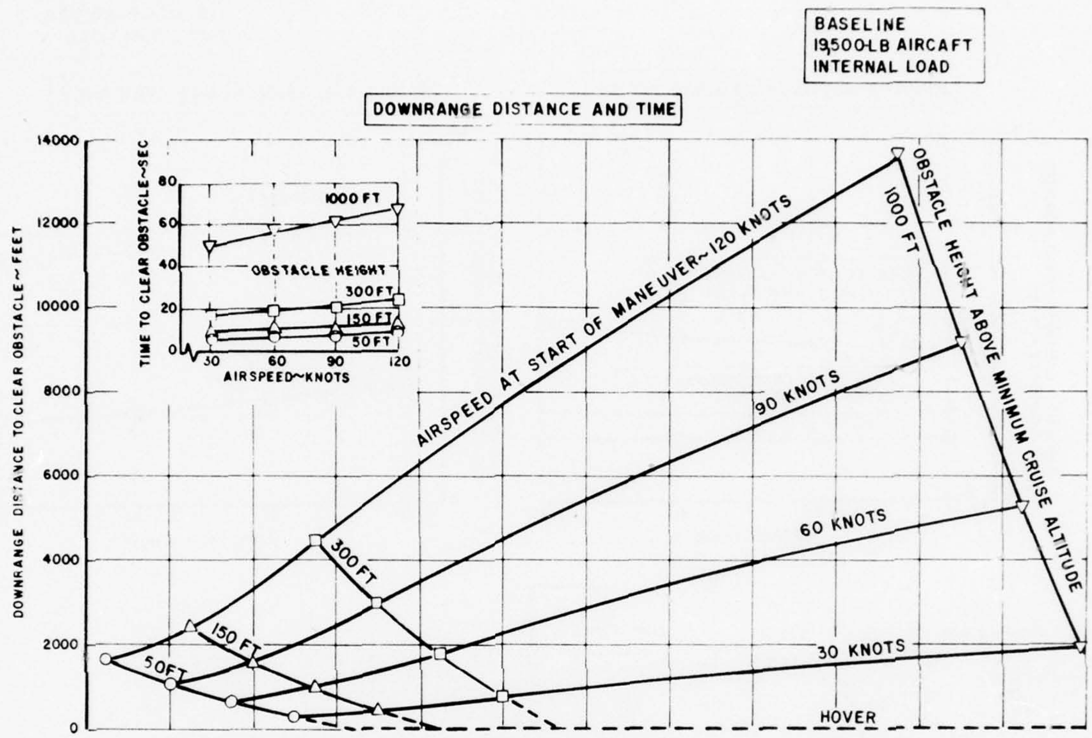


FIGURE 26. DOWNRANGE DISTANCE REQUIREMENTS FOR VERTICAL TERRAIN AVOIDANCE, INTERNAL LOAD BASELINE (19,500 LB)

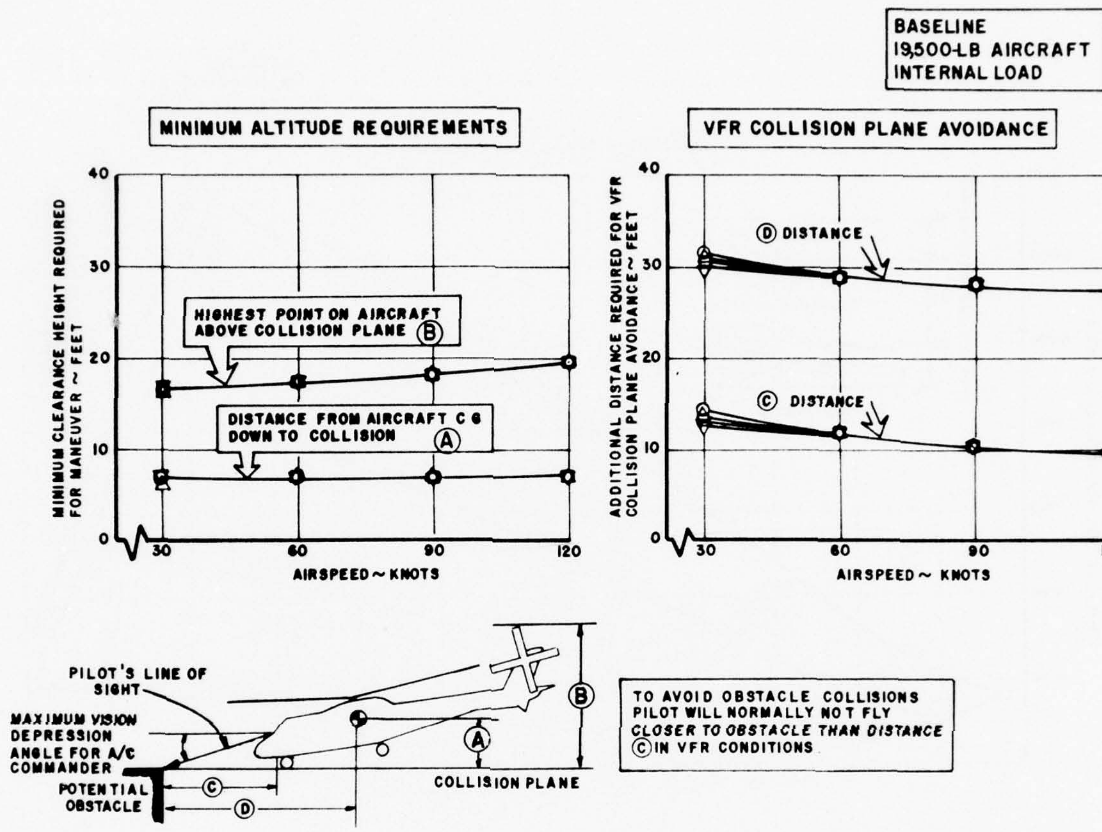


FIGURE 27. CLEARANCE REQUIREMENTS DURING VERTICAL TERRAIN AVOIDANCE, INTERNAL LOAD BASELINE (19,500 LB)

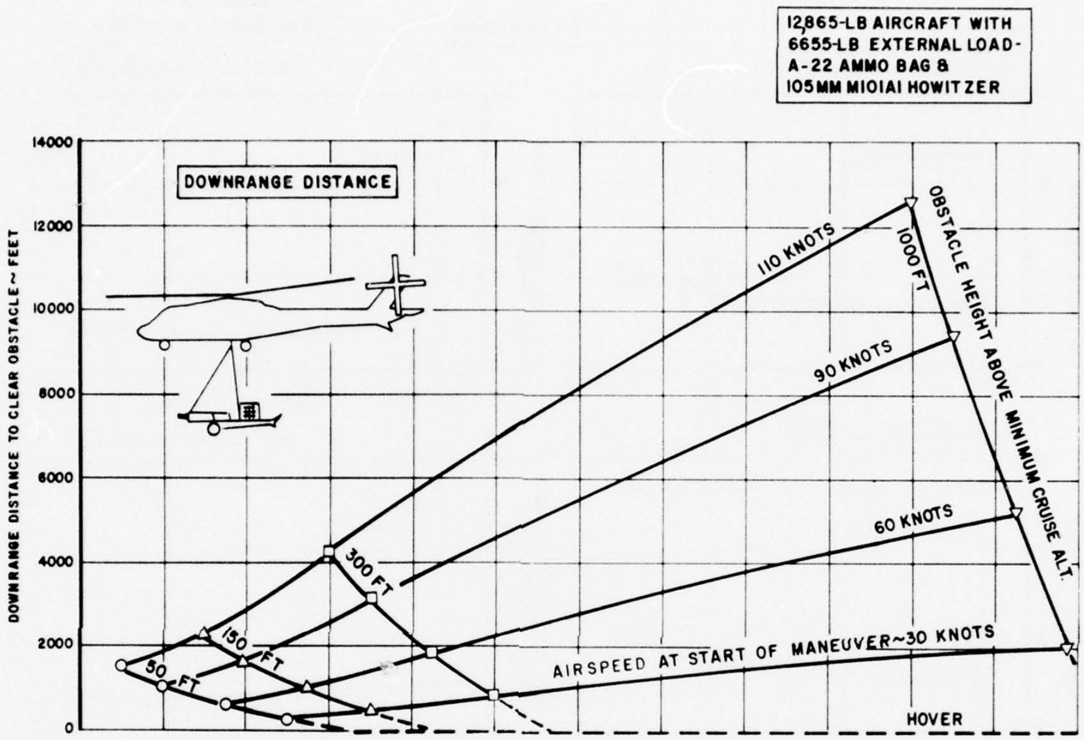


FIGURE 28. DOWNRANGE DISTANCE REQUIREMENTS FOR VERTICAL TERRAIN AVOIDANCE WITH EXTERNAL LOADS (105MM HOWITZER/A-22 AMMO BAG)

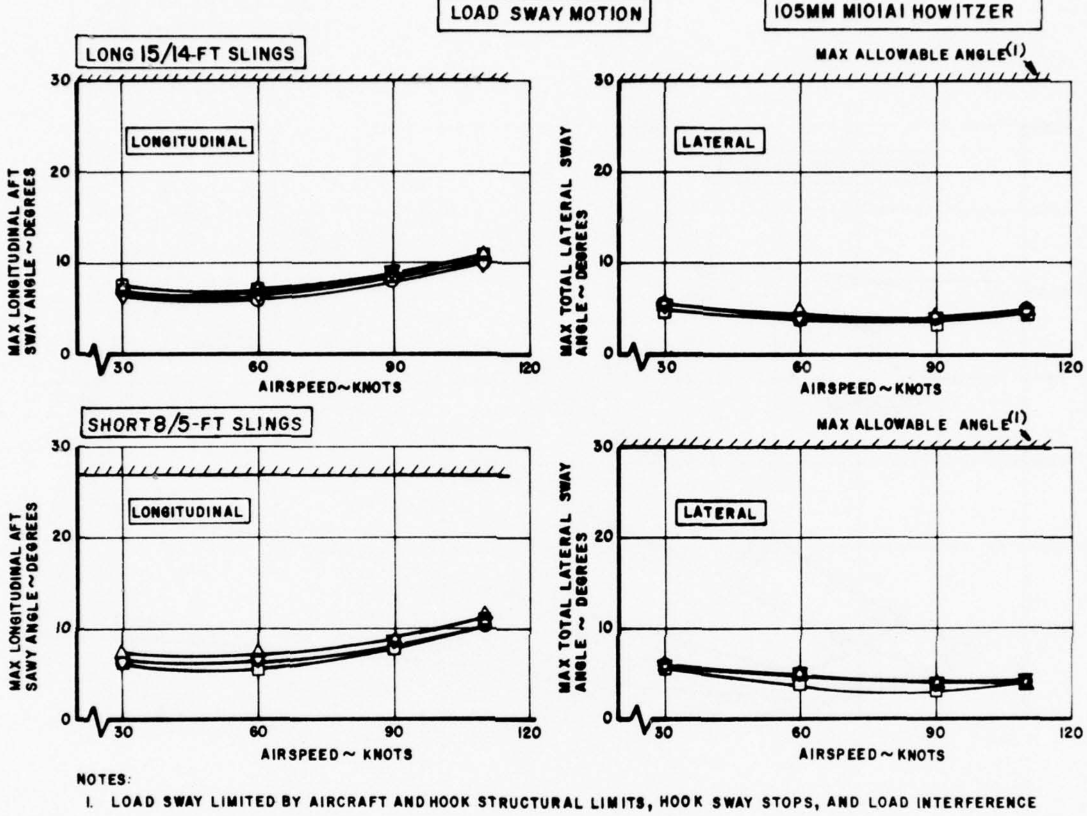
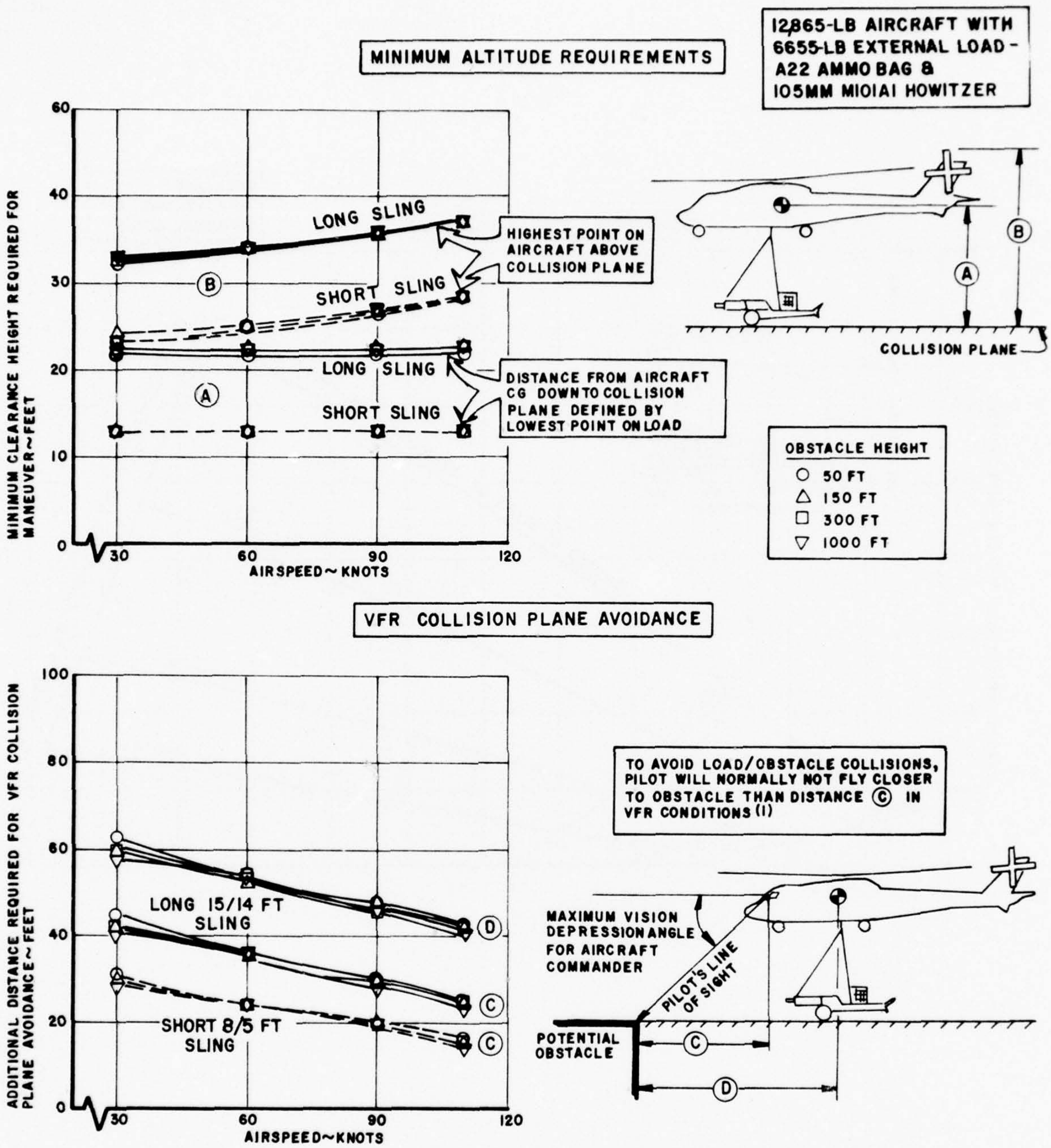


FIGURE 29. LOAD SWAY ANGLES DURING VERTICAL TERRAIN AVOIDANCE WITH EXTERNAL LOAD (105 MM HOWITZER / A-22 AMMO BAG)



NOTES:

1. MINIMUM CLEARANCE FROM OBSTACLE (C) MUST BE MAINTAINED FOR VFR MANEUVERING. TO COMPENSATE FOR THIS, AND LENGTH OF AIRCRAFT FROM C G TO NOSE, THESE DISTANCES MUST BE ACCOUNTED FOR IN DOWNRANGE DISTANCE.

FIGURE 30. CLEARANCE REQUIREMENTS DURING VERTICAL TERRAIN AVOIDANCE WITH EXTERNAL LOAD (105MM HOWITZER/ A-22 AMMO BAG)

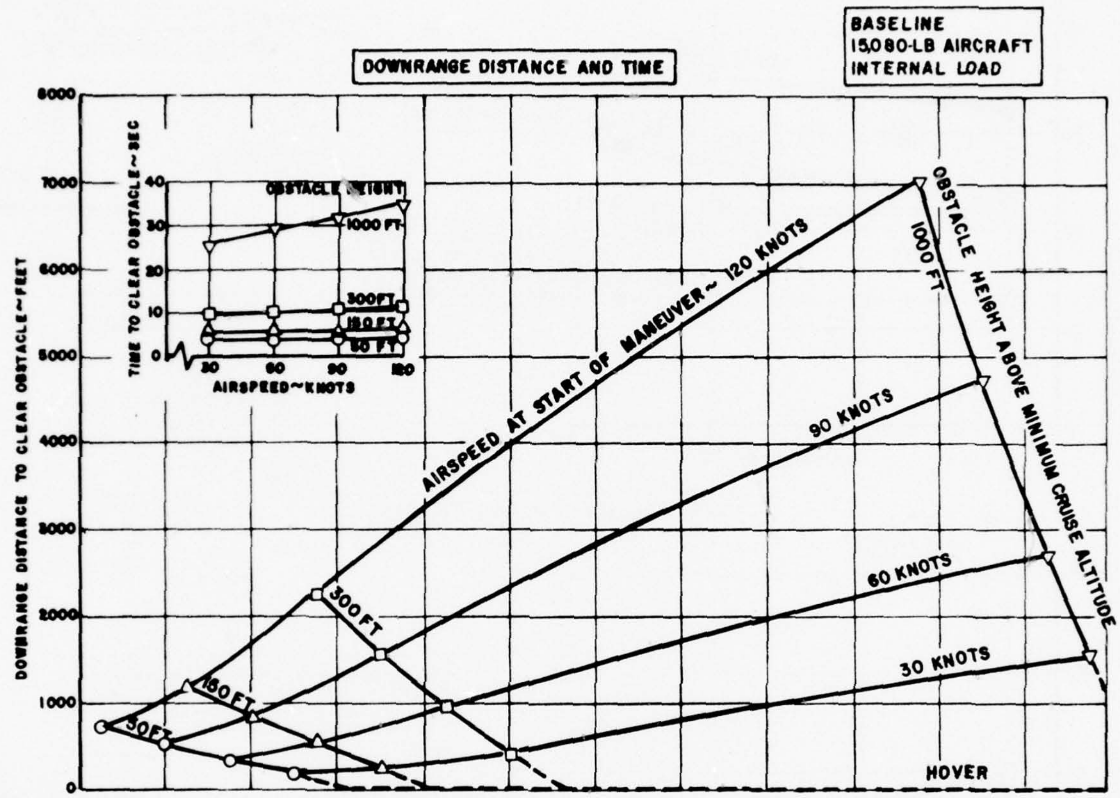


FIGURE 31. DOWNRANGE DISTANCE REQUIREMENTS FOR VERTICAL TERRAIN AVOIDANCE - INTERNAL LOAD BASELINE (15,080 LB)

3.2.4 Lateral Terrain Avoidance

This maneuver was not simulated for the UTTAS aircraft, but was evaluated extensively for the CH-47 during the companion terrain flying study (Reference 3). A pictorial representation of the maneuver is presented in Figure 32. General observations and limitations concluded from the CH-47 analysis are also annotated. Some restrictions in bank angle results at lower speeds.

3.2.5 Low-Level Cruise

As illustrated in Figure 33, and described in FM1-1, "Low level flight is conducted at a selected altitude where detection or observation of an aircraft, or of the points from which and to which it is flying, is avoided or minimized. The route is preselected and conforms generally to a straight line and a constant airspeed and indicated altitude".

In this mode of terrain flight, aircraft level flight speed characteristics are strongly influenced by external loads. Load drag slows the aircraft down when flying at either a power or transmission limit, and increased overall height of the aircraft/load combination requires higher cruise altitude. Cruise altitude requirements are further increased when flying at high speed, in order to provide an adequate safety margin between the load and the ground.

External load drag penalty is often as large as total helicopter parasite drag itself, and sometimes exceeds twice that of the aircraft for bluff body cargo shapes such as the 105mm howitzer and A-22 pack. The overall effect of adding external loads to the UTTAS in level flight is shown in Table 4, which compares maximum continuous power limited cruise speeds for all cargo configurations investigated in the terrain flying maneuver study.

Shown in the first column of the table are the estimated equivalent flat plate drag area (f_e) values for each load at its cruise angle of attack. To develop the total parasite drag penalty associated with carrying the load externally, f_e were corrected to account for aircraft drag variations caused by the increase nose down pitch attitudes flown to overcome load drag. The parasite power required for each load was added to level flight total power required (as defined by adjusted performance flight test results noted in Reference 13), to determine the cruise speed limits shown in the second column of the table. Note that airspeed is reduced approximately 10 knots when carrying the A-22 bag externally, and 34 to 36 knots for the 105mm howitzer/ A-22 pack combination.

As shown in the right-hand column in Table 4, addition of the A-22 load increases the cruise altitude requirement by up to 20 feet with the long suspension, and up to 9 feet with the short. Carrying the howitzer increases the cruise altitude anywhere from 5 to 13 feet.

3.2.6 Load Snag Considerations

Terrain flight with external loads leads to the obvious possibility of snagging the load on wires or dragging the load across the tops of trees. To assess the criticality of this problem, the simulation model was modified to include the effects of a load snag. Figure 34 presents the aircraft and load dynamic time histories following the snag of a A-22 ammo bag suspended on a standard long sling suspension. Two different snag conditions are shown.

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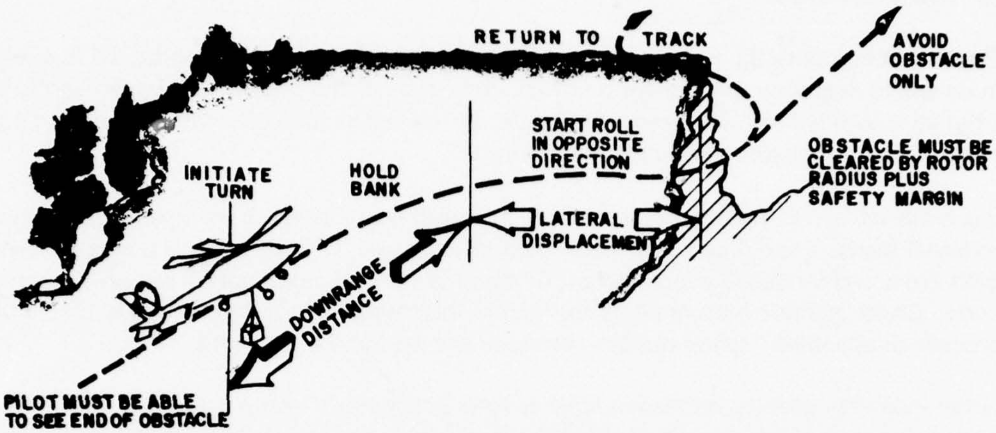
13. UH-61A PRIME ITEM DEVELOPMENT SPECIFICATION, Boeing Vertol Report D179-10541-1, 7 September 1976.



LIMITATIONS:

MANEUVERABILITY

- LATERAL/DIRECTIONAL LOAD MOTION LIMITS AIRCRAFT BANK ANGLE
- DOWNRANGE/LATERAL DISPLACEMENT DISTANCE
  - VISIBILITY

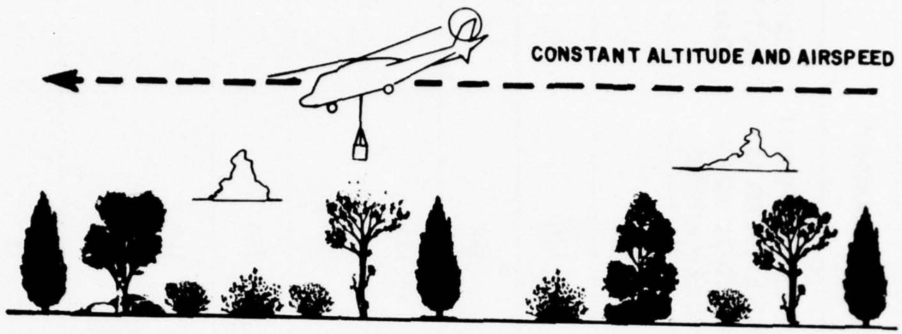
MASKING

- SIMILAR TO OTHER MANEUVERS

SPEED/TIME

- OBSTACLE SIZE
- VISIBILITY

FIGURE 32. LATERAL TERRAIN AVOIDANCE MANEUVER



LIMITATIONS:

SPEED

- LIMITED BY LOAD DRAG AND STABILITY

MASKING

- AIRCRAFT LOAD HEIGHT
- SAFETY MARGIN REQUIREMENT (INCREASES WITH SPEED AND REDUCED VISIBILITY)

FIGURE 33. LOW LEVEL TERRAIN FLIGHT

TABLE 4. UH-61A (UTTAS) LOW LEVEL CRUISE SUMMARY

CONFIGURATION			LOAD DRAG-EQUIVALENT FLAT PLATE AREA~FEET^2	MAX LEVEL FLIGHT CRUISE SPEED AS LIMITED BY XMSN TORQUE~KNOTS	MINIMUM CRUISE ALTITUDE - CG TO LOAD BOTTOM~FEET
15,080-LB GROSS WEIGHT	INTERNAL LOAD - BASELINE		0	164	8.0
	A-22 CARGO BAG	LONG (STD) SUSPENSION	15	154	26.3
		LONG (STD) SUSPENSION WITH AAELSS	19	152	27.6
		SHORT SUSPENSION	13	155	16.9
		SHORT SUSPENSION WITH AAELSS	17	153	16.9
19,500-LB GROSS WEIGHT	INTERNAL LOAD - BASELINE		0	154	7.4
	105MM HOWITZER AND PIGGYBACK A-22 BAG	LONG (STD) SUSPENSION	60	118	20.5
		LONG (STD) SUSPENSION WITH AAELSS	64	116	20.5
		SHORT SUSPENSION	58	120	12.7
		SHORT SUSPENSION WITH AAELSS	62	118	12.7

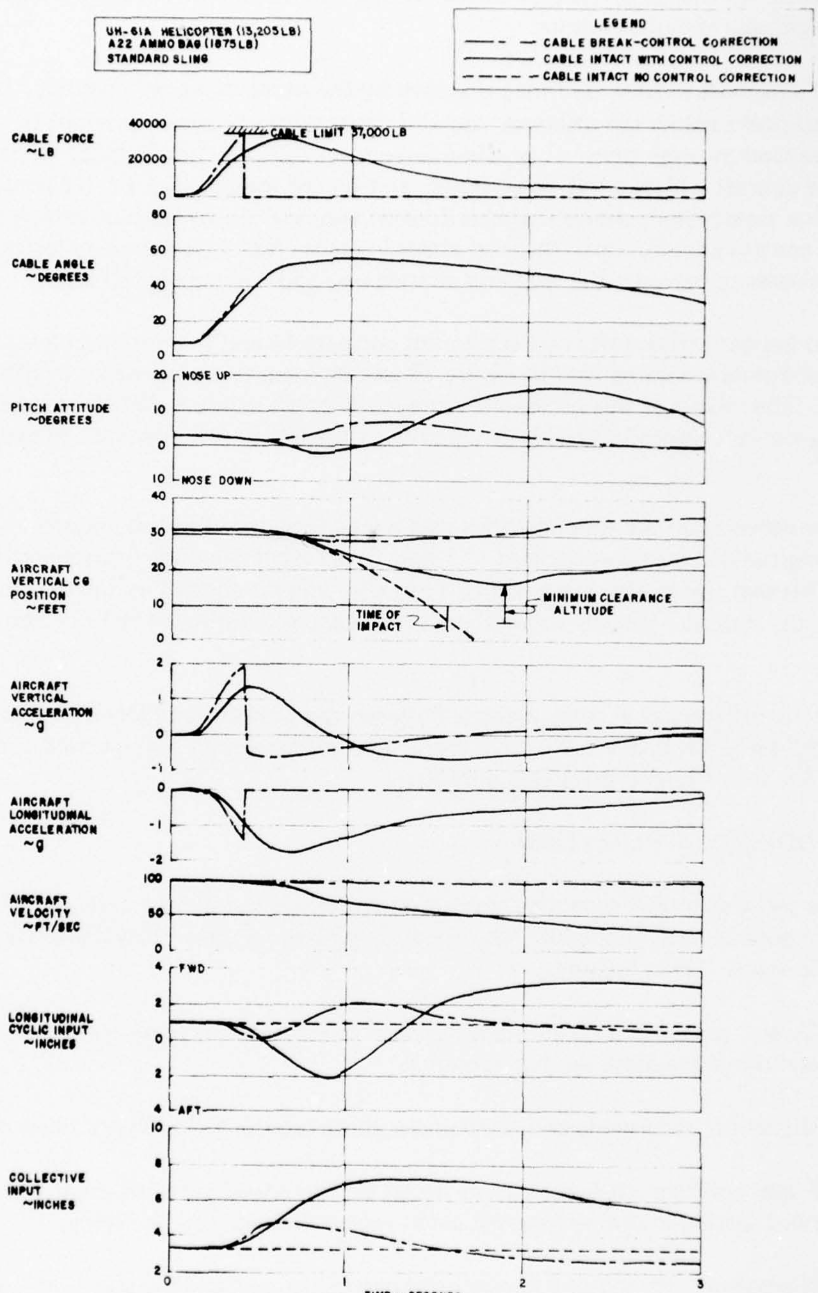


FIGURE 34. SIMULATED LOAD SNAG TRANSIENT RESPONSE

The first type of snag, denoted by the long and short dash line time histories, represents an obstacle strike wherein the load in the suspension exceeds the hook ultimate capability of 37,000 pounds. In this case, the load breaks away, and aircraft attitude and altitude are easily controlled with normal pilot inputs.

The second and most serious load snag is shown by the other two time histories. Here the suspension load peaks below the ultimate load and does not break away, as might be the case when dragging the load through trees. If no pilot corrective control action is taken (short dash time history) the aircraft will descend, pitch down, and hit the load in about 1-1/2 seconds as noted. The solid line time history shows that this descent and nose down attitude can be arrested with reasonable control activity, until the load either becomes free or is manually jettisoned. The minimum clearance between the load and aircraft was approximately 13 feet.

The time to impact without the necessary pilot corrections and the minimum clearance achieved with control inputs is summarized in Figure 35 for the loads and suspension lengths being considered. The results of this preliminary snag simulation indicate that an automatic jettison system may not be required. The control power of the UH-61A is adequate to maintain aircraft control.

It should be noted from the time histories that a snag load near the maximum allowable results in a high longitudinal deceleration level ($\approx$1.5g). To prevent the pilot from being accelerated forward in his seat, (with attendant difficulty in applying aft control inputs to arrest the maneuver), the shoulder harness should be locked manually during all NOE or contour terrain flight.

Because of the differences in rotor systems between the UH-60A and UH-61A resulting in a lower control power available for the UH-60A, it is recommended that a similar analysis be conducted for the production UTTAS aircraft.

3.3 TECHNOLOGY APPLICATION

Limitations and vision requirements for performing terrain flying have been identified in previous sections. In general, minimizing the identified limitations requires subsystems which fall into four specific areas. These include:

1. Cargo: suspension restraints which improve load stability and placement accuracy and minimize masking requirements.

2. Visionics: to provide and/or improve vision capability in IMC or night operations.

3. Flight control: control systems which aid low-speed handling qualities and reduce pilot workload during external cargo acquisition and terrain flying.

4. Navigation: to improve navigational capability, particularly short- and medium-range terrain information for flight and ground-path selection, location, and/or bearing to destination. Detection and identification of obstacles (such as poles, towers, etc.) is also desired.

Table 5 lists the candidate concepts which offer a potential for minimizing the terrain flight limitations of the UTTAS helicopter.

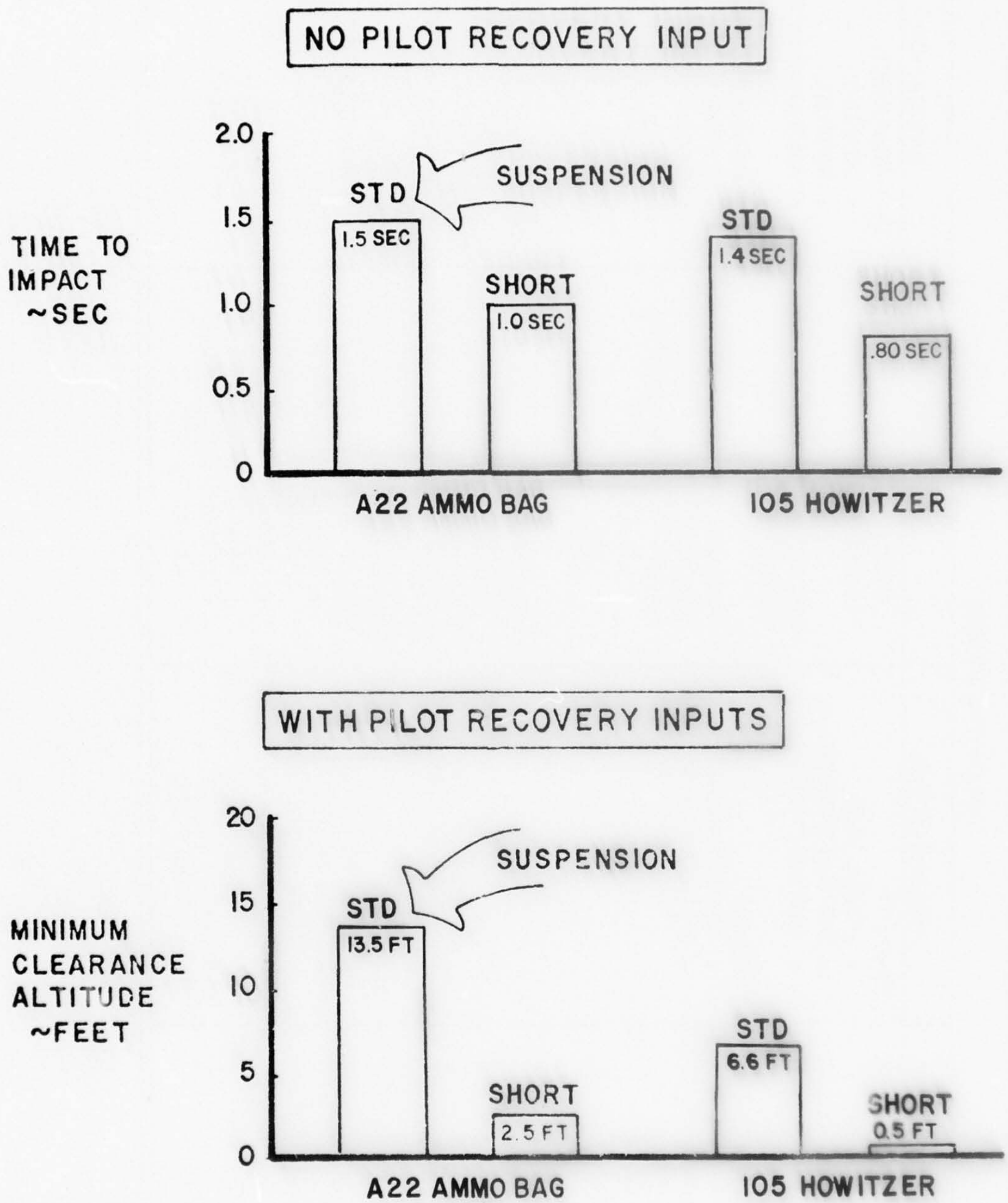


FIGURE 35. SUMMARY OF LOAD SNAG RESPONSE CHARACTERISTICS

TABLE 5. CANDIDATE CONCEPTS FOR MINIMIZING TERRAIN FLIGHT LIMITATIONS			
MAJOR SUBSYSTEMS			
CARGO	FLIGHT CONTROL	VISIONICS	NAVIGATION
SUSPENSION RESTRAINTS • SLING LENGTH • DUAL HOOK LOAD STABILIZATION JETTISON CAPABILITY – SNAG • AUTOMATIC • MANUAL	STABILITY • HOVER HOLD • GROUND SPEED HOLD • ALTITUDE HOLD CONTROL • GROUND SPEED • CREWMAN CONTROL	COCKPIT LIGHTING REQUIREMENTS WINDSHIELD GLARE REDUCTION PASSIVE SIGHT AMPLIFICATION • NIGHT VISION GOGGLES • LLL-TV • FLIR • *FLMRAD* WIRE DETECTION • LOTAWS	SELF CONTAINED • DOPPLER • INERTIAL • AIR DATA NAV SYS GROUND COOPERATIVE • LORAN • OMEGA
SYSTEMS NOT CONSIDERED			
LOAD SNUBBING SYSTEM	GUIDANCE • AUTO APPROACH • AUTO DEPARTURE • TERRAIN FOLLOWING • TERRAIN AVOIDANCE DISPLAYS • GROUND SPEED	ACTIVE SIGHT AMPLIFICATION • TERRAIN CLEARANCE RADAR • TERRAIN FOLLOWING RADAR • TERRAIN AVOIDANCE RADAR	DISPLAYS • MOVING MAP

3.3.1 Cargo System Concepts

The primary restrictions to UTTAS terrain flight capability are associated with the basic coupled motions of the external load, increased minimum required operational altitudes, and susceptibility to load snags. Improvements in these areas are required before full utilization can be made of UTTAS terrain flying capability. The cargo system concepts identified as offering a potential solution toward this end include the following:

1. Shortened suspension lengths
2. Load stabilization
3. Dual hook restraints

3.3.1.1 Shortened Sling Lengths

Previous analysis presented in Section 3.2 indicates that application of shortened sling technology offers good potential for reducing the overall masking requirements of the aircraft and load. The magnitude of masking height reduction achieved obviously depends upon the configuration and type of cargo being carried, as shown for the two UTTAS terrain flying study loads illustrated in Figures 36 and 37. Both of these sling loads exhibit an approximate 1/3 decrease in masking when suspended on short slings with the aircraft pitch attitude held level.

Table 6 compares masking and collision plane to cg height requirements (developed in Section 3.2) with the aircraft performing typical dash and vertical terrain avoidance maneuvers for long, short and internal load configurations. While improvements are noted in projected height requirements, anticipated reductions in load instability and peak load motions did not occur with shortened sling restraints. This result, coupled with lower permissible sway angle limits prior to airframe collision, reduces terrain flight maneuverability and precludes application of sling shortening as the only item used in achieving full capability with external loads. Automatic load stabilization was then considered as an approach for regaining lost maneuverability.

3.3.1.2. Load Stabilization System

Technology for providing automatic load stabilization has been developed and extensively flight-evaluated for use on CH-47 type helicopters. One of the concepts, known as the Active Arm External Load Stabilization System (AAELSS), has been demonstrated twice in the past 5 years as indicated in References 4 and 5. The system utilizes two hydraulically powered arms mounted in tandem beneath the helicopter, which automatically move in response to load pendular motion to provide damping ratios on the order of 30 percent of critical. AAELSS reduces load motion by about 2/3, and eliminates any tendency for pilot-induced oscillation (PIO) of the load to occur in reduced visibility conditions encountered at night or in IMC.

Application of the AAELSS concept for UTTAS load damping is shown in the single arm configuration illustrated in Figure 38. The system consists of a removable supporting frame bolted to the aircraft floor, from which a telescoping arm is suspended on a universal joint. Lateral and longitudinal arm motion is produced by hydraulic actuators connected between the arm and mounting frame at floor level. The lower arm installation utilizes a T-bar configuration with

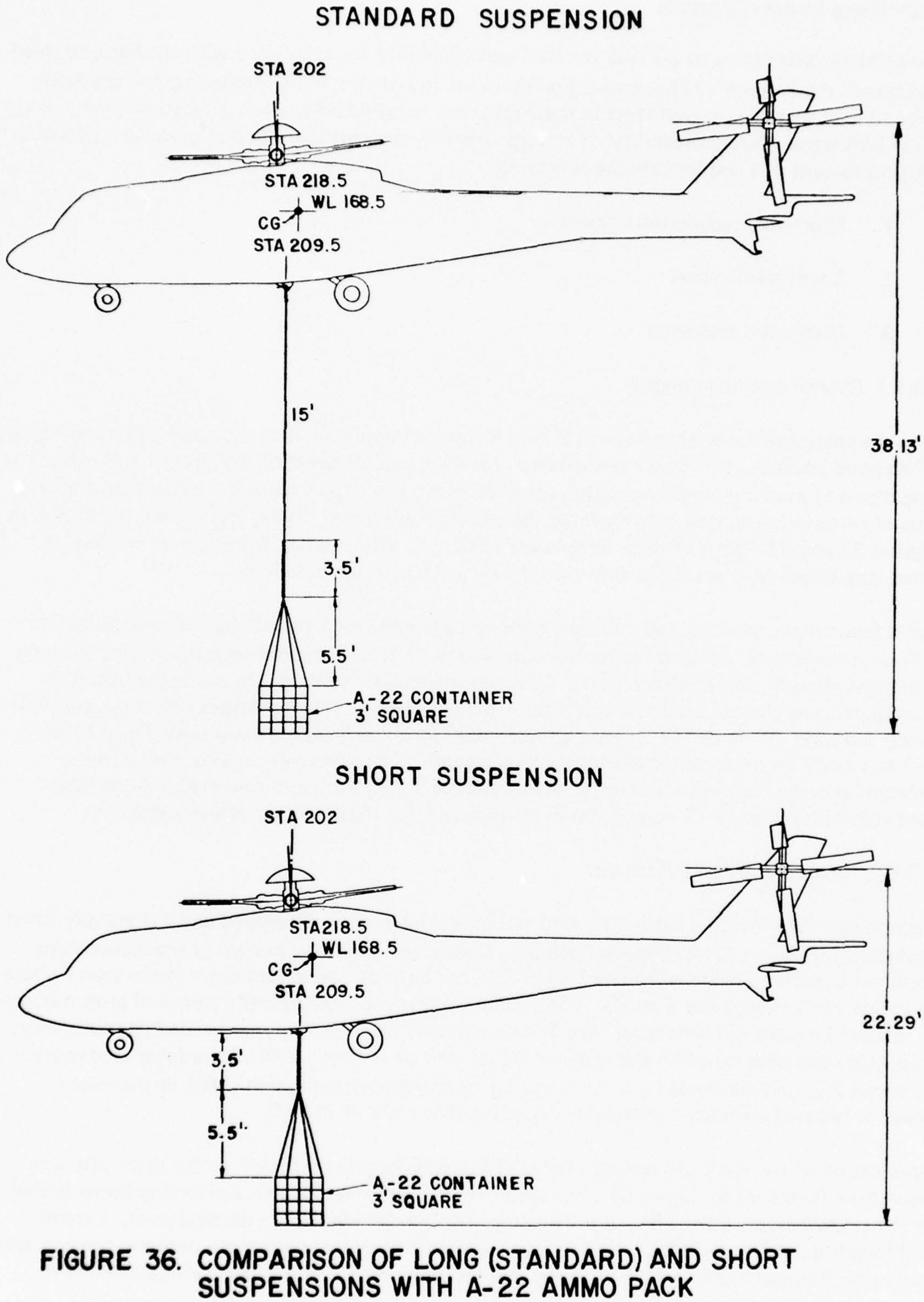


FIGURE 36. COMPARISON OF LONG (STANDARD) AND SHORT SUSPENSIONS WITH A-22 AMMO PACK

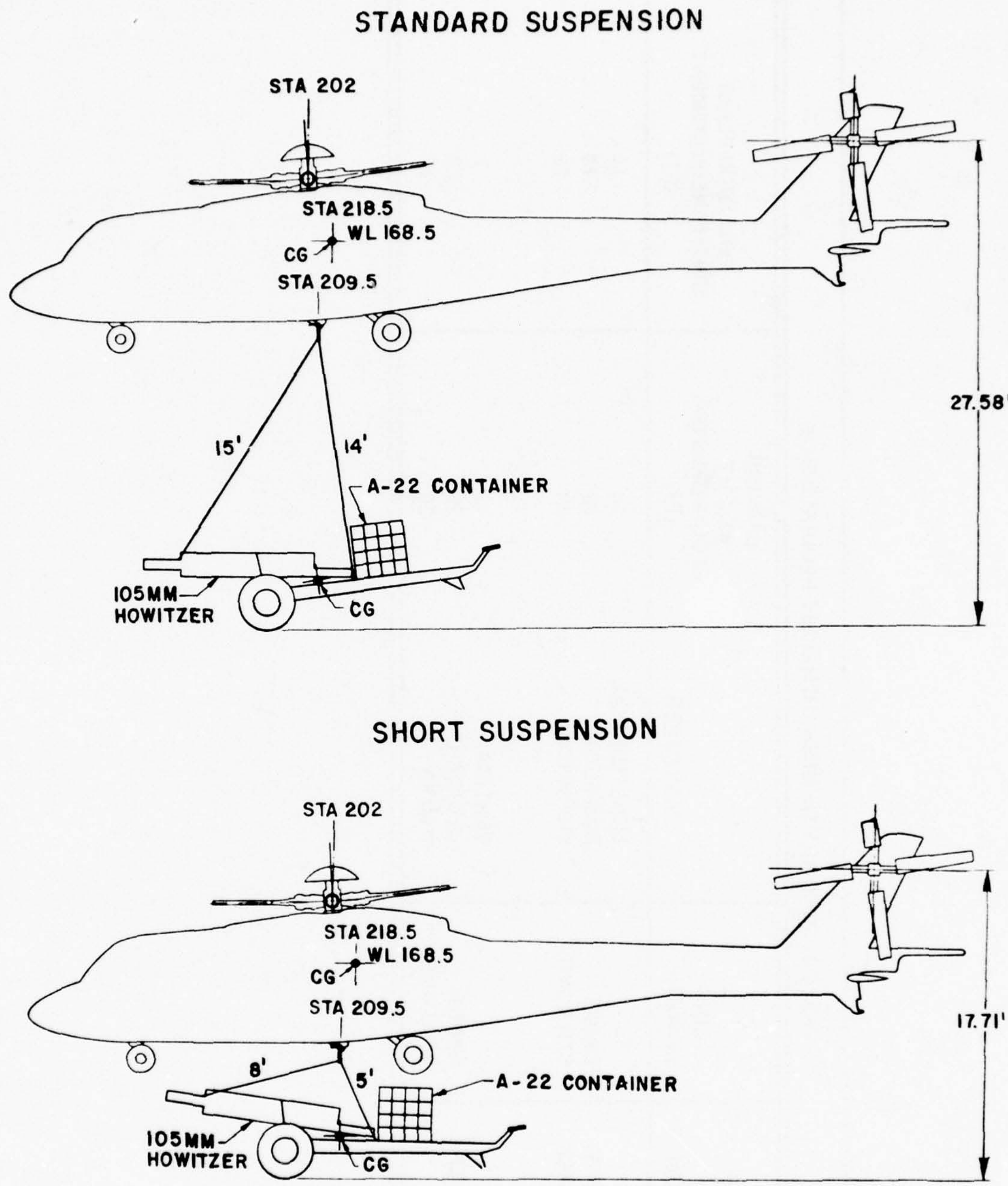


FIGURE 37. COMPARISON OF STANDARD AND SHORT SUSPENSION FOR 105MM HOWITZER

TABLE 6. SUMMARY OF MINIMUM HEIGHT REQUIREMENTS

LOAD CONFIGURATION	SLING LENGTH	MANEUVER	MASKING HEIGHT REQUIREMENTS (FT)	COLLISION PLANE HEIGHT REQUIREMENT (FT)
INTERNAL	–	LONGITUDINAL	25	11
105MM HOWITZER	SHORT	DASH USING	28	13
& A-22 *PIGGYBACK* PACK	STD LONG	$\pm 10^{\circ}$ PITCH	38	23
INTERNAL	–	VERTICAL	18	7
105MM HOWITZER	SHORT	AVOIDANCE	25	13
& A-22	STD LONG	@ 60 KN	34	22

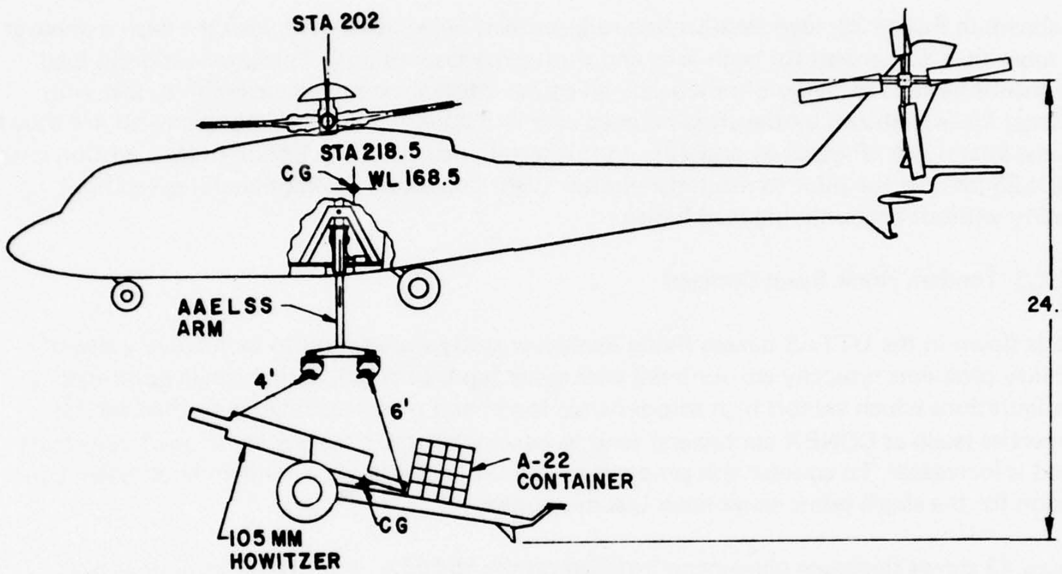


FIGURE 38. ACTIVE ARM EXTERNAL LOAD STABILIZATION SYSTEM CONCEPT

cargo hooks on either end to constrain yaw motion.

When not in use, the lower T-section is held against the aircraft bottom surface, but is deployed into the locked position shown in Figure 38 after load pickup. A detailed description of the UTTAS AAELSS is presented in Section 4.0. The system concept is not confined to any particular cargo configuration since it can readily carry artillery (as shown), CONEX containers, or possibly multiple loads such as A-22 ammunition bags while operating. The single arm UTTAS AAELSS would perform essentially the same functions as the dual arm CH-47 device in cutting down load sway motion and reducing pilot workload appreciably.

As shown in Figure 39, load stabilization reduces load swing associated with the dash maneuver by more than 50 percent for both long and short sling suspensions. This attenuation in load excursions permits recovery of practically all of the internal cargo maneuverability lost with external loads as shown by the cross-hatched area in Figure 40. Similar improvements are shown for the lateral jink (Figures 41 and 42). In this terrain maneuver, reduction in load motion with AAELSS permits the pilot to reach the aircraft flight handbook 35-knot lateral speed limit quickly without encountering load limits.

3.3.1.3 Tandem Hook Beam Concept

Loads flown in the UTTAS terrain flying maneuver study were found to be relatively free of stability problems typically encountered with some types of cargo. Other single point load configurations which exhibit high aerodynamic forces and moments relative to their inertia properties (such as CONEX containers) tend to become unstable (especially in yaw) as aircraft speed is increased. To counter this problem on the UTTAS aircraft, a tandem hook beam conversion for the single point cargo hook was developed.

Figure 43 shows the beam conversion installed on the UH-61A, with the 105mm howitzer load suspended on tandem slings. This type of cargo restraint virtually eliminates load yaw motion in flight, and in so doing allows the pilot to position the loads more accurately and quickly for deposit on the battlefield. Tandem hook load restraint enjoys another advantage over single point suspension, and this occurs because the load tends to remain in a level attitude as it swings fore and aft. Some single point loads (particularly large artillery pieces) tend to strike either the barrel or trails through the aircraft bottom when short suspensions are used to improve battlefield masking.

Design and operation of the tandem hook beam concept is covered in more depth in Section 4.0.

3.3.1.4 Effectiveness Ranking

To reflect the overall effectiveness of each cargo system concept evaluated, a ranking scheme was developed utilizing masking requirements, maneuver capability, and airspeed as the principal parameters of consideration. The results of the simulated maneuvers were assessed relative to the capability of the aircraft with the internal load baseline. A representative displacement or obstacle-avoidance height was selected for each of the various terrain flying modes. Longitudinal and lateral translations of 500 feet, and a vertical avoidance distance of 150 feet were chosen for the ranking process.

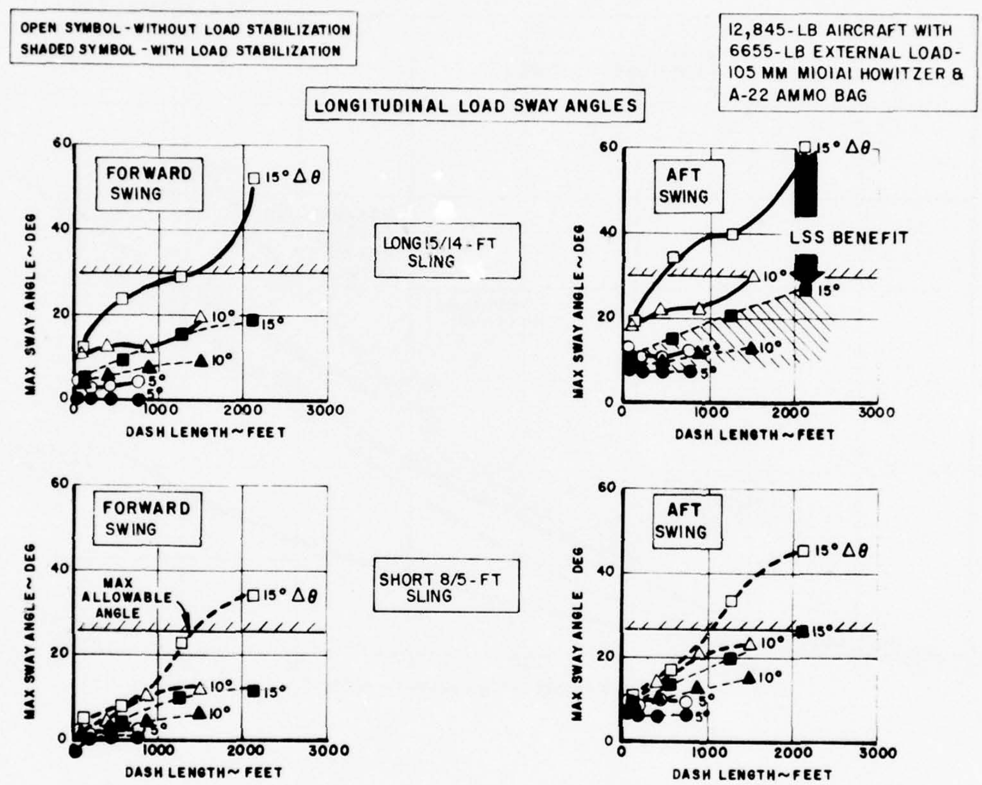


FIGURE 39. DASH LOAD SWAY COMPARISON WITH AND WITHOUT LOAD STABILIZATION

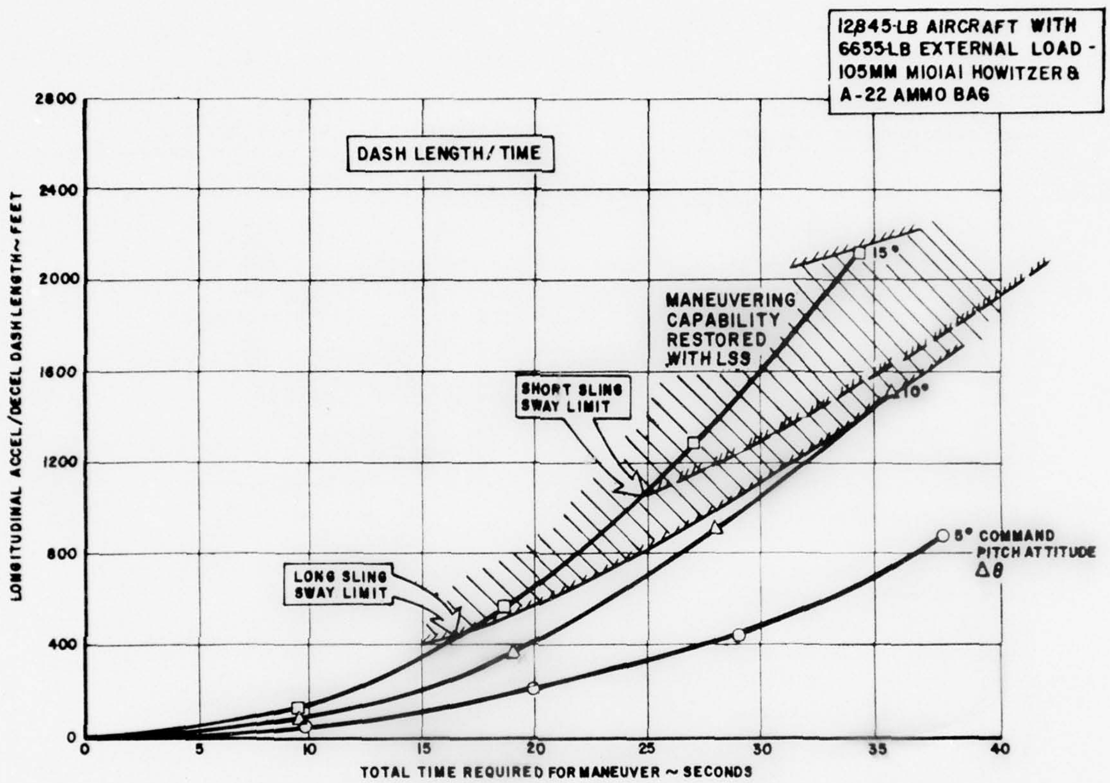


FIGURE 40. DASH MANEUVER CAPABILITY WITH LOAD STABILIZATION

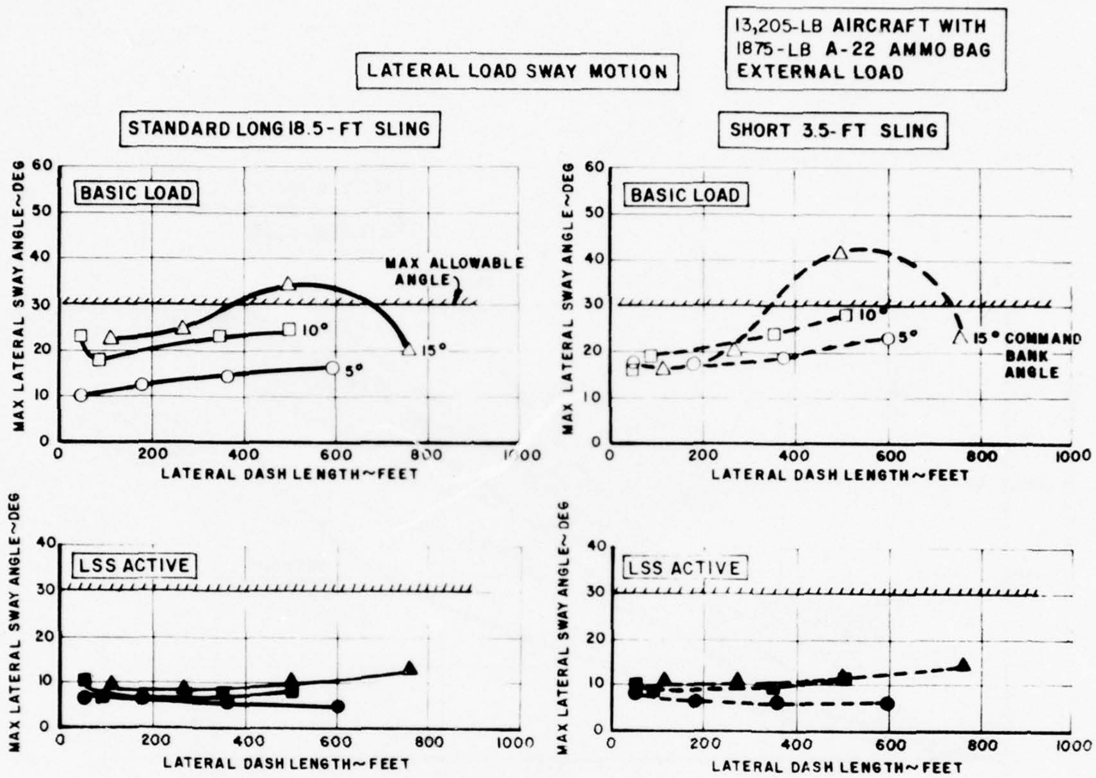


FIGURE 41. LATERAL JINK LOAD SWAY COMPARISON WITH AND WITHOUT LOAD STABILIZATION

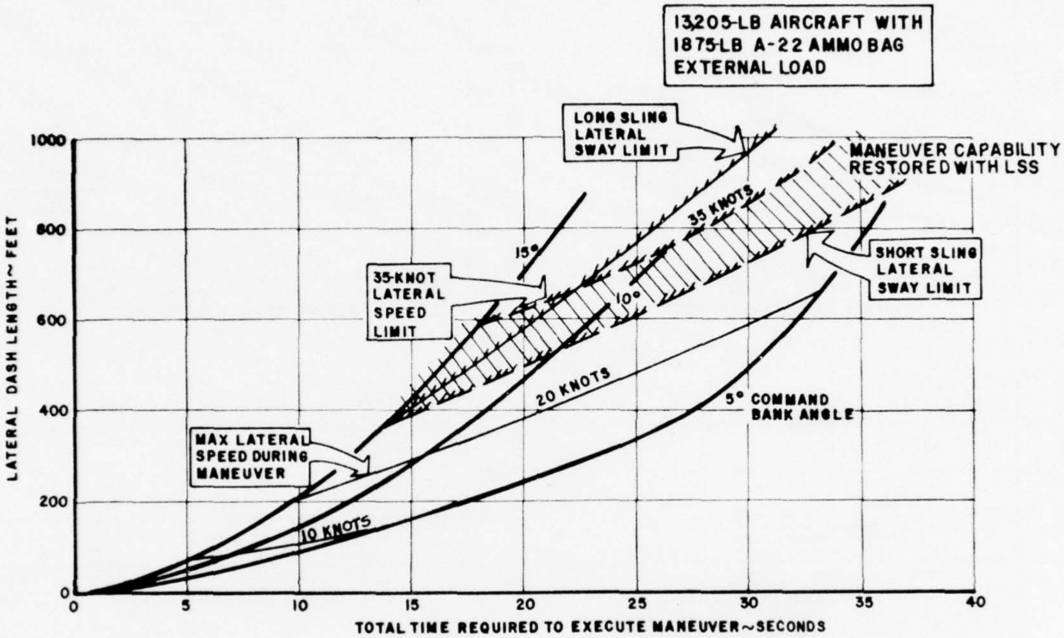


FIGURE 42. LATERAL JINK MANEUVER CAPABILITY WITH LOAD STABILIZATION

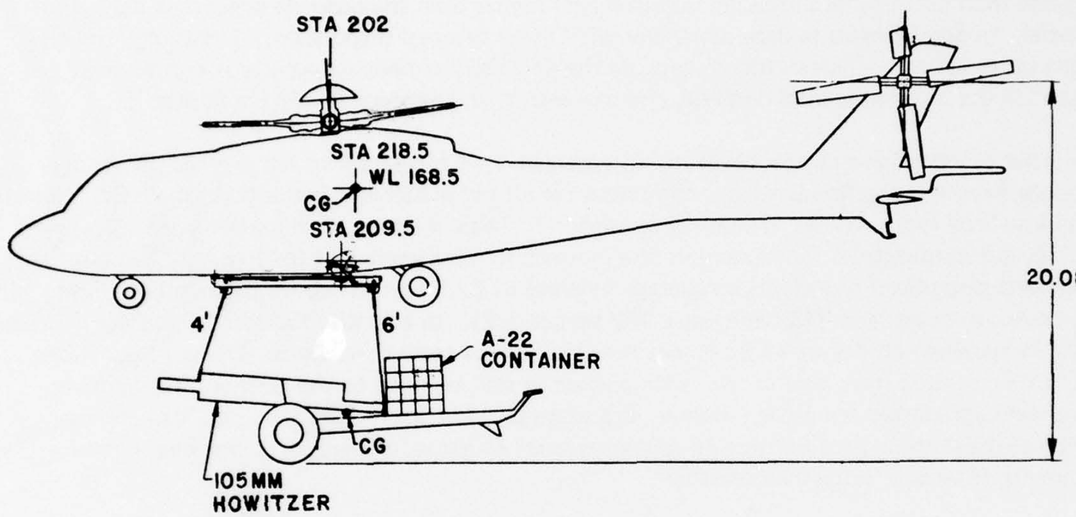


FIGURE 43. UTTAS TANDEM HOOK BEAM CONCEPT

Masking considerations were again defined by minimum altitude above the collision plane. Maneuverability was ranked by either maximum permissible attitude command (in pitch or roll), minimum time to translate, or minimum downrange distance to clear the obstacle. The ranking associated with the low-level-flight mode considered maximum permissible airspeed as limited by maximum continuous power.

Table 7 summarizes the results obtained with the A-22 bag and 105mm howitzer/A-22 pack loads. By setting the level obtained from the baseline at unity, a ratio of results for each of the load suspensions, compared to the baseline value, was calculated. All boxes in the table contain both the actual magnitude and the corresponding ratio to the baseline. Comparisions greater than unity reflect masking requirements higher than the baseline or less maneuver potential. In several cases (a dash maneuver with the shortened suspension), a masking level less than unity appears. This occurred because the permissible maneuverability is significantly less than for the internal loaded baseline, and as a result, less masking height is required.

In order to establish a clearer relationship between the configurations, an average percentage change from the baseline level was computed for all the maneuvers included in the NOE, contour and low-level flight modes. These are presented in Table 8 where both masking and maneuverability are summarized. For example, the increase in masking height for the A-22 bag with standard suspension represents an average increase of 67.5 percent above the baseline during nap-of-the-earth maneuvers [(33 percent + 102 percent)/2]. In a similar fashion, an average degradation in maneuverability of 44.2 percent resulted for the same conditions. The configurations were then ranked from one to five, with a value of one assigned to the configuration with the smallest degradation from the baseline. Equal weighting factors were included for each maneuver, since at the present time no mission scenarios exist which would support a stronger need for one segment of terrain flying over another.

In addition to the quantitative rankings in Table 8, susceptibility to night or IMC-associated PIO of the load is also annotated.

As indicated earlier, the greatest potential for increased UTTAS terrain flying effectiveness appears to lie in the area of reducing load pendular sway motion, through use of an automatic stabilization (AAELSS) system. This concept has been developed and tested extensively on tandem rotor aircraft, and should involve low risks for UTTAS adaptation. As indicated in Table 8, AAELSS is most effective when used in conjunction with short suspensions to minimize masking requirements. Like the tandem hook beam concept, AAELSS also has the potential for eliminating load yaw motion for cargo with strong aerodynamic characteristics.

Table 9 compares the two simulation study loads and various suspension concepts, emphasizing additional areas such as mission effectiveness, system complexity, and developmental requirements. Overall mission effectiveness for daylight operations was determined by averaging the masking and maneuverability ratings for all terrain flight modes listed in Table 8. Again, from this summary, the short suspension AAELSS application appears most effective for the study loads.

The initial development of cargo systems aimed at UTTAS terrain flight enhancement should also include design and test of the tandem hook beam concept (discussed in Section 4.0) because of its relative simplicity and probable low cost. The system would weight only about 130 pounds and could probably be brought to a flight test status in minimum time when compared to

TABLE 7. COMPARISON OF MANEUVER REQUIREMENTS FOR SUSPENSION CONCEPTS ANALYZED

CONFIGURATION			NAP OF THE EARTH						CONTOUR			LOW LEVEL	
			LONGITUDINAL DASH				LATERAL JINK		VERTICAL AVOIDANCE			CONSTANT ALTITUDE	
			OVERALL AIRCRAFT + LOAD HEIGHT FT	MINIMUM CG HEIGHT FT	MAXIMUM PITCH ATTITUDE DEG	MINIMUM TIME SEC	MAXIMUM ROLL ATTITUDE DEG	MINIMUM TIME SEC	MINIMUM ALTITUDE ABOVE OBSTACLE ROTOR FT	MINIMUM ALTITUDE ABOVE OBSTACLE CG FT	MINIMUM DOWN-RANGE DISTANCE FT	MINIMUM CG ALTITUDE FT	MAXIMUM SPEED KT
15,080 LB GR WT		INTERNAL LOAD BASELINE	36.9 1.0	16.3 1.0	>20.0 1.0	15.3 1.0	>20.0 1.0	15.0 1.0	54.5 1.0	42.7 1.0	561 1.0	8.0 1.0	164 PWR 1.0
15,080 LB GR WT	WITH A-22 AMMO BAG	STD SUSPENSION	49.0 1.33	33.0 2.02	11.5 1.74	20.0 1.31	13.0 1.54	17.7 1.18	75.5 1.38	63.2 1.48	616 1.10	26.3 3.26	154 PWR 1.06
15,080 LB GR WT	WITH A-22 AMMO BAG	STD SUSPENSION WITH LSS	50.6 1.37	33.0 2.02	15.0 1.33	17.3 1.13	15.0 1.33	16.4 1.09	75.5 1.38	63.2 1.48	616 1.10	27.3 3.41	152 PWR 1.08
15,080 LB GR WT	WITH A-22 AMMO BAG	REVISED SHORT SUSPENSION	33.5 0.91	18.9 1.16	9.0 2.22	22.6 1.48	11.0 1.82	20.0 1.33	61.5 1.13	49.2 1.15	613 1.09	16.9 2.1	155 PWR 1.06
15,080 LB GR WT	WITH A-22 AMMO BAG	REVISED SHORT SUSPENSION WITH LSS	37.0 1.0	19.2 1.18	15.0 1.33	17.3 1.13	15.0 1.33	16.4 1.09	61.5 1.13	49.2 1.15	613 1.09	16.9 2.1	153 PWR 1.07
19,500 LB GR WT		INTERNAL LOAD BASELINE	36.0 1.0	16.0 1.0	>20.0 1.0	15.0 1.0	—	—	53.5 1.0	42.7 1.0	1003 1.0	7.4 1.0	154 PWR 1.0
19,500 LB GR WT	WITH 105MM HOWITZER AND A-22 AMMO BAG	STD SUSPENSION	40.5 1.12	22.0 1.38	14.5 1.38	18.0 1.20	—	—	64.2 1.20	52.4 1.23	1052 1.05	20.5 2.77	118 PWR 1.31
19,500 LB GR WT	WITH 105MM HOWITZER AND A-22 AMMO BAG	STD SUSPENSION WITH LSS	40.5 1.12	22.0 1.38	15.0 1.33	17.0 1.13	—	—	64.2 1.2	52.4 1.23	1052 1.05	20.5 2.77	116 PWR 1.33
19,500 LB GR WT	WITH 105MM HOWITZER AND A-22 AMMO BAG	REVISED SHORT SUSPENSION	30.5 0.85	13.0 0.81	15.0 1.33	17.0 1.13	—	—	54.8 1.02	43.0 1.01	1012 1.01	12.7 1.72	120 PWR 1.28
19,500 LB GR WT	WITH 105MM HOWITZER AND A-22 AMMO BAG	REVISED SHORT SUSPENSION WITH LSS	30.5 0.85	13.0 0.81	15.0 1.33	17.0 1.33	—	—	54.8 1.02	43.0 1.01	1012 1.01	12.7 1.72	118 PWR 1.31
			MASKING		MANEUVERABILITY				MASKING		MANEUVER ABILITY		
			500 FT LONGITUDINAL TRANSLATION				500 FT LATERAL TRANSLATION		150 FT OBSTACLE AVOIDANCE AT 60 KT			VMAX = TORQUE LIMIT OR MAX DEMO IN TEST	

ACTUAL MAGNITUDE → XXX
X.XX ← COMPARISON TO BASELINE

TABLE 8. TERRAIN FLYING EFFECTIVENESS

		CONFIGURATION	NAP OF THE EARTH MASKING	NAP OF THE EARTH MANEUVERABILITY	CONTOUR MASKING	CONTOUR MANEUVERABILITY	LOW LEVEL MINIMUM CRUISE CG ALTITUDE	LOW LEVEL SPEED	NIGHT/IMC PIO SUSCEPTABILITY
15,080 LB GR WT		INTERNAL LOAD BASELINE	0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
15,080 LB GR WT	A22 AMMO BAG	STD SINGLE POINT SUSPENSION	67.5% (3)	44.2% (3)	43% (3)	10% (3)	229% (3)	6% (1)	HIGH WITH INCREASED LOAD WEIGHT
15,080 LB GR WT	A22 AMMO BAG	STD SINGLE POINT SUSPENSION WITH LSS	69.5% (4)	22% (1)	43% (3)	10% (3)	241% (4)	8% (4)	NEGLIGIBLE
15,080 LB GR WT	A22 AMMO BAG	REVISED SHORT SUSPENSION	3.5% (1)	72% (4)	14% (1)	9% (1)	110% (1)	6% (1)	HIGH WITH INCREASED LOAD WEIGHT
15,080 LB GR WT	A22 AMMO BAG	REVISED SHORT SUSPENSION WITH LSS	9% (2)	22% (1)	14% (1)	9% (1)	110% (1)	7% (3)	NEGLIGIBLE
19,500 LB GR WT		INTERNAL LOAD BASELINE	0%	0%	0%	0%	0%	0% POWER LIMIT	NONE
19,500 LB GR WT	105MM HOWITZER + A22	STD SINGLE POINT SUSPENSION	.25% (3)	29% (4)	22% (3)	5% (3)	177% (3)	31% (2)	HIGH
19,500 LB GR WT	105MM HOWITZER + A22	STD SINGLE POINT SUSPENSION WITH LSS	25% (3)	23% (1)	22% (3)	5% (3)	177% (3)	33% (4)	NEGLIGIBLE
19,500 LB GR WT	105MM HOWITZER + A22	REVISED SHORT SUSPENSION	17% BETTER (1)	23% (1)	1.5% (1)	1.0% (1)	72% (1)	28% (1)	HIGH
19,500 LB GR WT	105MM HOWITZER + A22	REVISED SHORT SUSPENSION WITH LSS	17% BETTER (1)	23% (1)	1.5% (1)	1.0% (1)	72% (1)	31% (2)	NEGLIGIBLE

% PERFORMANCE DEGRADATION FROM INTERNAL LOADED BASELINE

NUMERICAL ORDERING

TABLE 9. UTTAS EXTERNAL LOAD SYSTEM SUMMARY

CONFIGURATION			LIMITATIONS IMPROVEMENT		ADDITIONAL SYSTEM COMPLEXITY	DEVELOPMENT STATUS	REQUIRED DEVELOPMENTAL PROGRAM
			DAYLIGHT EFFECTIVENESS (PERCENT)	NIGHT/IMC EFFECTIVENESS			
15,080-LB GR WT	INTERNAL LOAD BASELINE		0	SIMILAR			
15,080-LB GR WT	A22 AMMO BAG	STD SINGLE POINT SUSPENSION	66.6	DEGRADED	NONE	AVAILABLE	TERRAIN FLIGHT EVALUATION
15,080-LB GR WT	A22 AMMO BAG	STD SINGLE POINT SUSPENSION WITH LSS	65.6	SIMILAR	ACTIVE ARM LOAD STABILIZATION SYSTEM & AIRCRAFT INTERFACING	DESIGN CONCEPT	PRELIMINARY DESIGN THRU FLIGHT TESTING
15,080-LB GR WT	A22 AMMO BAG	REVISED SHORT SUSPENSION	35.75	DEGRADED	NONE	AVAILABLE	TERRAIN FLIGHT EVALUATION
15,080-LB GR WT	A22 AMMO BAG	REVISED SHORT SUSPENSION WITH LSS	28.5	SIMILAR	ACTIVE ARM SYSTEM	DESIGN CONCEPT	PRELIMINARY DESIGN THRU FLIGHT TESTING
19,500-LB GR WT	INTERNAL LOAD BASELINE		0	SIMILAR			
19,500-LB GR WT	105 MM HOWITZER + A22	STD SINGLE POINT SUSPENSION	48.2	DEGRADED	NONE	AVAILABLE	TERRAIN FLIGHT EVALUATION
19,500-LB GR WT	105 MM HOWITZER + A22	STD SINGLE POINT SUSPENSION WITH LSS	47.5	SIMILAR	ACTIVE ARM SYSTEM	DESIGN CONCEPT	PRELIMINARY DESIGN THRU FLIGHT TESTING
19,500-LB GR WT	105 MM HOWITZER + A22	REVISED SHORT SUSPENSION	18.1	DEGRADED	NONE	AVAILABLE	TERRAIN FLIGHT EVALUATION
19,500-LB GR WT	105 MM HOWITZER + A22	REVISED SHORT SUSPENSION WITH LSS	18.6	SIMILAR	ACTIVE ARM SYSTEM	DESIGN CONCEPT	PRELIMINARY DESIGN THRU FLIGHT TESTING
CONEX ETC		TANDEM HOOK BEAM	18.1	DEGRADED	DUAL HOOK ADAPTER DEVICE & STRUCTURE INTERFACES	DESIGN CONCEPT	PRELIMINARY DESIGN THRU FLIGHT TESTING

comparable development for a single arm AAELSS. In addition the tandem hook beam weight and consequent payload penalty is estimated to be only about 1/3 of that of a production AAELSS unit.

A further concept not explored in the UTTAS study, but covered in some depth in the CH-47 program (Reference 3), would be some type of self-hoisting/load snubbing device to attach the load to the aircraft bottom. A system of this type might be used to rapidly pick up loads such as CONEX containers, and then to snub them against the aircraft to eliminate load motion, and thus minimize overall load/helicopter masking and cruise height requirements. Although not specifically covered in this report, development of a snubbing concept for UTTAS size helicopters should be pursued, to ensure maximum utilization of the external cargo potential of these aircraft.

3.3.2 Vision Enhancement

3.3.2.1 Visionics Systems

At present, the capability for performing limited nighttime terrain flying missions with external loads exists to some degree, but varies considerably from load to load. Such factors as the availability of moonlight or starlight influence the success of these missions, along with pilot proficiency and/or familiarity with the terrain over which the flight is to be conducted. Most night VFR terrain flights must be flown at very low speed in order to provide sufficient time for terrain avoidance after obstacles are identified.

When nighttime ambient lighting conditions are poor due to overcast sky or lack of moonlight, terrain flight becomes progressively more difficult until finally complete darkness or IMC conditions preclude terrain flying altogether. In view of the long-standing U.S. Army desire for an around-the-clock/all-weather aviation capability, the Army has been sponsoring development of visionics systems over the past several years which aid the pilot in seeing outside the aircraft at night or in inclement weather.

To explore what might be possible as regards future UTTAS terrain flight operations in night and IMC conditions, a survey of potential visionics systems and their capabilities was made. This survey included a visit to the U.S. Army Night Vision Laboratory (NVL) at Fort Belvoir, Virginia, to confirm estimated visionics system performance (described later), and to determine what new systems were currently under development. Figure 44 summarizes the relative VMC and IMC performance of the systems surveyed and gives an indication of current developmental status and cost.

Three of the systems described in Figure 44 were selected for application in the terrain flying study. These included:

- AN/PV-5 night vision goggles (NVG) with 40-degree field of view
- 360-line forward-looking infrared (FLIR) with 30- by 40-degree field of view using a helmet-mounted display
- Laser obstacle terrain avoidance and warning system (LOTAWS) for wire avoidance.

CANDIDATES		VMC CAPABILITY					IMC CAPABILITY			SYSTEM STATUS/COST
SYSTEM	TYPE	DAY	1/2 MOON	1/4 MOON	STARLIGHT (CLOUDLESS)	TOTAL DARKNESS	BROAD TERRAIN FEATURES	SMALL OBSTACLE + RANGE INFO	WIRE DETECTION	
NAKED EYE		EYE								
NIGHT VISION GOGGLES (NVG)	PASSIVE		NVG							• IN PRODUCTION • COST ≈ $ 10,000
LOW LIGHT LEVEL TV (LLL-TV)	PASSIVE			LLL-TV						• PROTOTYPES FLYING
FORWARD-LOOKING INFARED (FLIR)	PASSIVE				FLIR					• PROTOTYPE FLYING • AAH PROTOTYPES UNDER DEVELOPMENT • COST ≈ $ 60-80,000
FORWARD-LOOKING MICROWAVE RADIOMETRY (FLMRAD)	PASSIVE				FLMRAD					• EARLY STAGES OF DEVELOPMENT
LASER OBSTACLE TERRAIN AVOIDANCE & WARNING SYS. (LOTAWS)	ACTIVE					LOTAWS				• PROTOTYPE CONCEPT FLOWN ON CH-53 FOR WIRE DETECTION
RADAR	ACTIVE					RADAR				• PROTOTYPES FLOWN • NOE/CONTOUR APPLICATIONS QUESTIONABLE

FIGURE 44. POTENTIAL VISIBILITY IMPROVEMENT CANDIDATES

The first two of these systems permit the pilot to see well enough to avoid larger obstacles when performing terrain flight at night, but their resolution is generally inadequate for detecting very small objects in the path of the aircraft such as wires. To accomplish this task, the Army has been developing the LOTAWS concept (Reference 14), which has the potential for identifying 1/8-inch standard Army telephone wire at ranges up to 1,500 feet.

Experimental NVG and FLIR systems have been flown on a number of aircraft in terrain flight experiments of the type described in References 6 and 7. Improved versions of both systems will be standard equipment on the YAH-64 Armed Attack Helicopter currently being developed by the Army. Two types of FLIR's are being installed on this aircraft; a pilot's night-vision system (PNVS) for pilot navigation and terrain avoidance, and a target-acquisition/designation system (TADS) for the copilot.

Uprated third-generation NVG systems, employing an improved image intensifier tube to increase either resolution or field of view, are being developed specifically for aviation applications. These goggles and the PNVS developed for the AAH are likely candidates for future application in any UTTAS nighttime terrain flying visionics package. Each is essentially a passive light or infrared amplification device, which is intended primarily for nighttime use. FLIR has some capability in IMC conditions, but performance degrades somewhat in cloud (as influenced by such things as water-vapor aerosol size.)

Microwave radiation systems such as FLMRAD (see Figure 44) should have better performance than current FLIR systems in IMC conditions. FLMRAD systems are only in early stages of development, however, and will therefore probably not be available in time for inclusion in any UTTAS visionics package.

Although LOTAWS is an active system, it could easily be operated in bursts from a trigger on the aircraft control stick. As envisioned for application in a UTTAS terrain flying visionics display, the LOTAWS image could be superimposed on the FLIR display and then used with some type of image-holding feature which is updated each time the trigger is depressed. The pilot could look ahead for wires as often as he thought necessary, but would not be constrained to continuous LOTAWS use in areas where the air defense threat was high.

Because of the continuous active signal emitted by terrain-following and avoidance radars, they were not considered for application in the UTTAS terrain flying visionics system. In addition, radar displays currently available are not particularly useful for obstacle avoidance in the NOE mode.

3.3.2.1.1 System Performance – To quantify how well the terrain flying maneuvers might be performed while using the visionics systems just described, range capability for each device was estimated for several different obstacle (target) sizes varying from tracked vehicles to large terrain features. Figure 45 compares NVG and FLIR detection range performance for targets ranging up to 100 meters square. Detection range is the greatest distance at which an obstacle is first detected, and where a pilot might put in initial control movements to avoid an obstacle. It is greater than the recognition range where the object can be identified. A 50-percent probability of exceedance means that the object would be detected at the range shown (or greater) during 50 percent of the available nighttime hours in the mid-European environment.

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14. Del Boca, R. L., et al, THE DEVELOPMENT AND TESTING OF A LASER OBSTACLE TERRAIN AVOIDANCE WARNING SYSTEM (LOTAWS), United Technologies Research Center; Technical Paper, Contract No. DAA-B07-72-C-0145, U. S. Army Electronics Command, Fort Monmouth, New Jersey, June 1976.

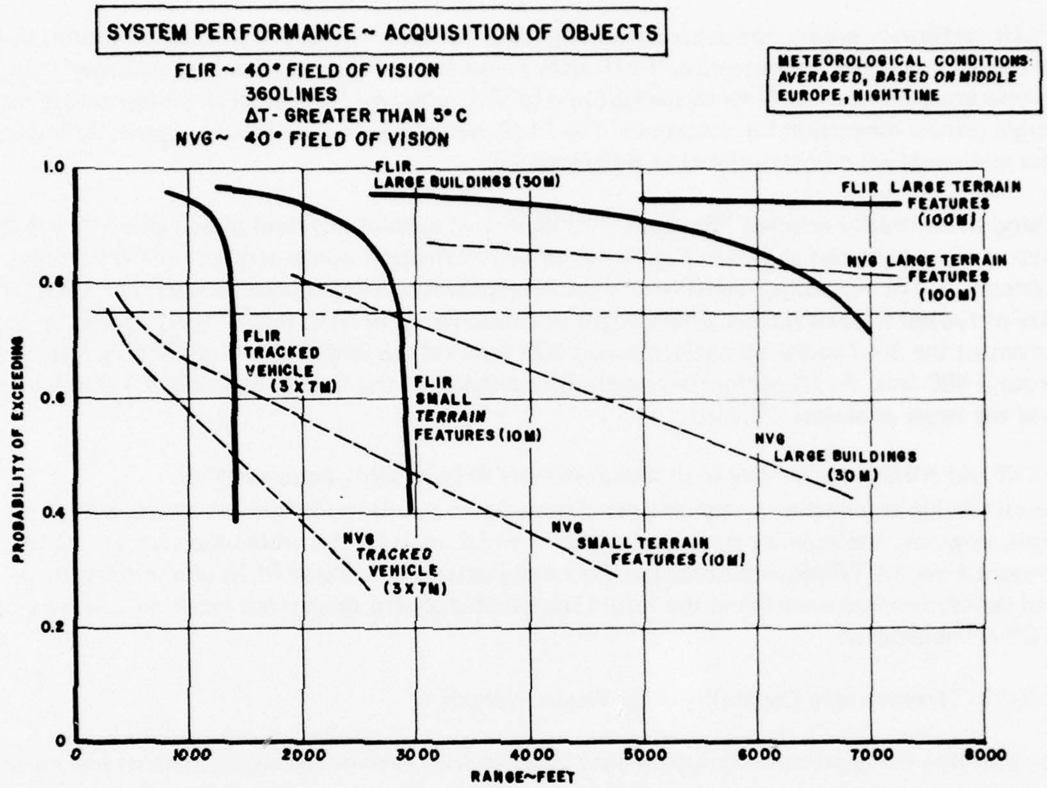

FIGURE 45. FLIR AND NVG SYSTEM PERFORMANCE FOR OBJECT DETECTION

As shown in the figure, potential range of the FLIR is several times greater than with the NVG, and this performance advantage increases with obstacle size at the higher probability levels. The probability of exceedance with the NVG was computed, accounting for the nighttime lighting and average atmospheric conditions in mid-Europe. The low exceedance probabilities or the higher ranges represent the clear night/full moon levels, whereas the higher exceedance probabilities approach full IMC.

FLIR performance does not depend upon lighting, but does reflect the weather variations used to develop the NVG performance. FLIR data presented in Figure 45 assumes a constant obstacle temperature differential from its background of 5°C, and two line pairs (16 pixels) across the target critical dimension for detection. The FLIR performance calculations roughly followed the mathematical model outlined in Reference 15.

Using an arbitrarily selected 75-percent probability of exceedance level of being able to see the two smallest obstacles shown in Figure 45, range information was generated for the visionics systems used in evaluating nighttime maneuver capability. These obstacles would be about the size of typical trees or houses which might be encountered in NOE flight. NVG should be able to detect the 3-x 7-meter obstacle at about 320 feet and the larger 10x10-meter target at around 480 feet. FLIR performance permits detection of the smaller obstacle at 1,380 feet and the larger at almost 1/2 mile.

FLIR and NVG systems have been shown in tests to be roughly equivalent for terrain flying applications in lighting conditions down to 1/4 moonlight. With less available light, however, the superior range capability of FLIR makes it the preferable system. At the present time, LOTAWS is not available for combined use with these FLIR and NVG systems, but should become available in the future since a breadboard system has flown successfully on a CH-53 helicopter.

3.3.2.2 Terrain Flight Capability With Vision Systems

Quantifying the degree of maneuverability possible with each of the above systems was made by superimposing the range capability, associated with the 75-percent probability of visual detection, on the range plots for each maneuver. In interpreting the data from Figures 46 to 48, it is useful to note that the pilot would be able to see up to the distances annotated for each system. That is, with NVG, he could see a tracked vehicle up to about 320 feet and small terrain features to 480 feet. Since it is assumed that the pilot must be able to see his destination before starting a maximum-performance maneuver, the available maneuver envelope with the vision system is then simply the portion of the curve below the vision range line.

Figure 46 summarizes restrictions imposed on the dash maneuver by each of the vision systems. A nominal capability of 30 knots maximum velocity exists for the NVG, while FLIR and LOTAWS restrict maximum speeds to approximately 60 knots. Similar limitations result for the lateral jink maneuver summarized in Figure 47. For the vertical terrain-avoidance maneuver shown in Figure 48, the capability of NVG would provide visual detection adequate

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15. NIGHT VISION LABORATORY STATIC PERFORMANCE MODEL FOR THERMAL VIEWING SYSTEMS, Research and Development Technical Report ECOM 7043, United States Army Electronics Command, Fort Monmouth, New Jersey, April 1975.

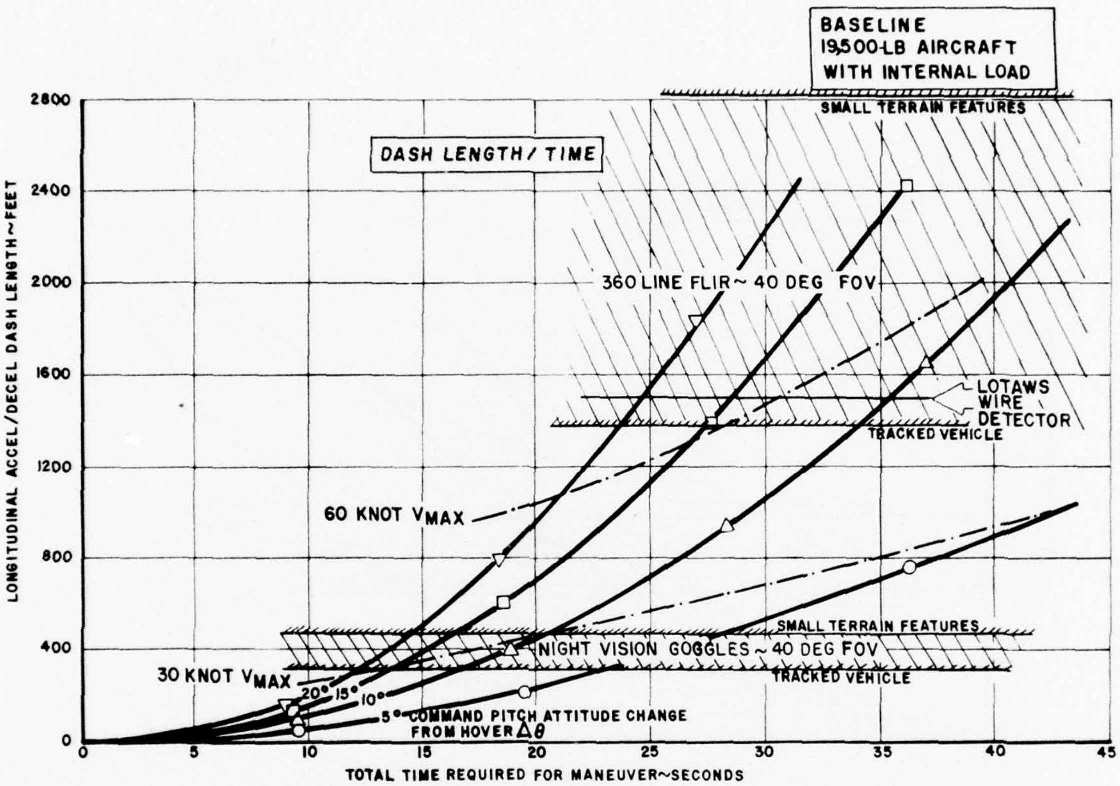

FIGURE 46. DASH MANEUVER CAPABILITY WITH FLIR AND NVG VISIONIC SYSTEMS

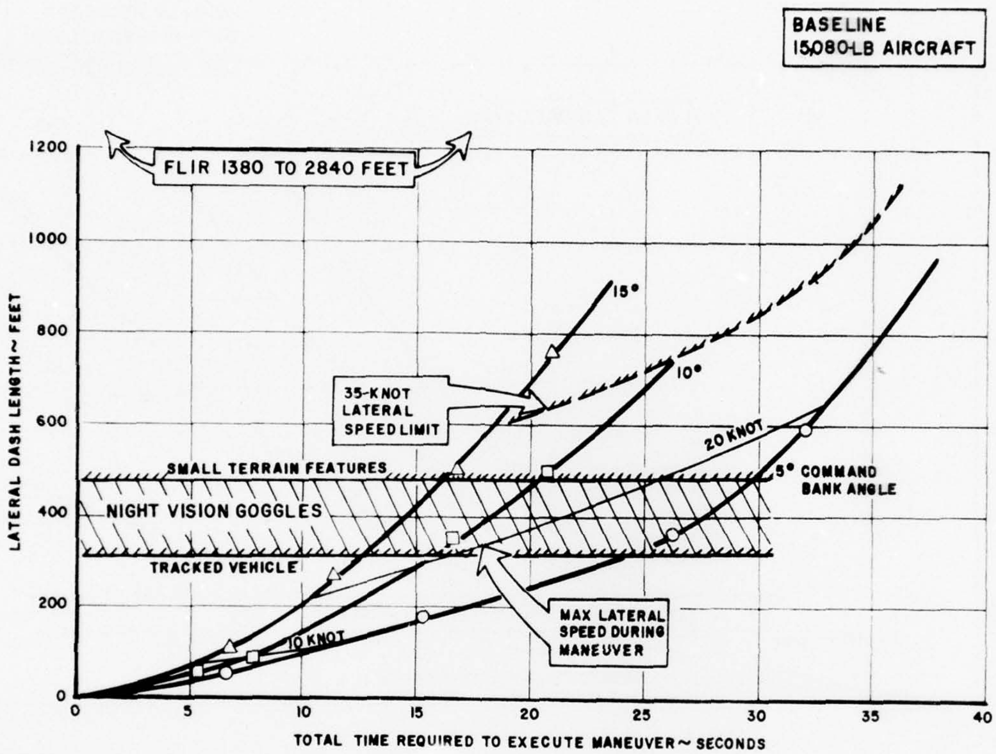

FIGURE 47. LATERAL JINK CAPABILITY WITH FLIR AND NVG VISIONIC SYSTEMS

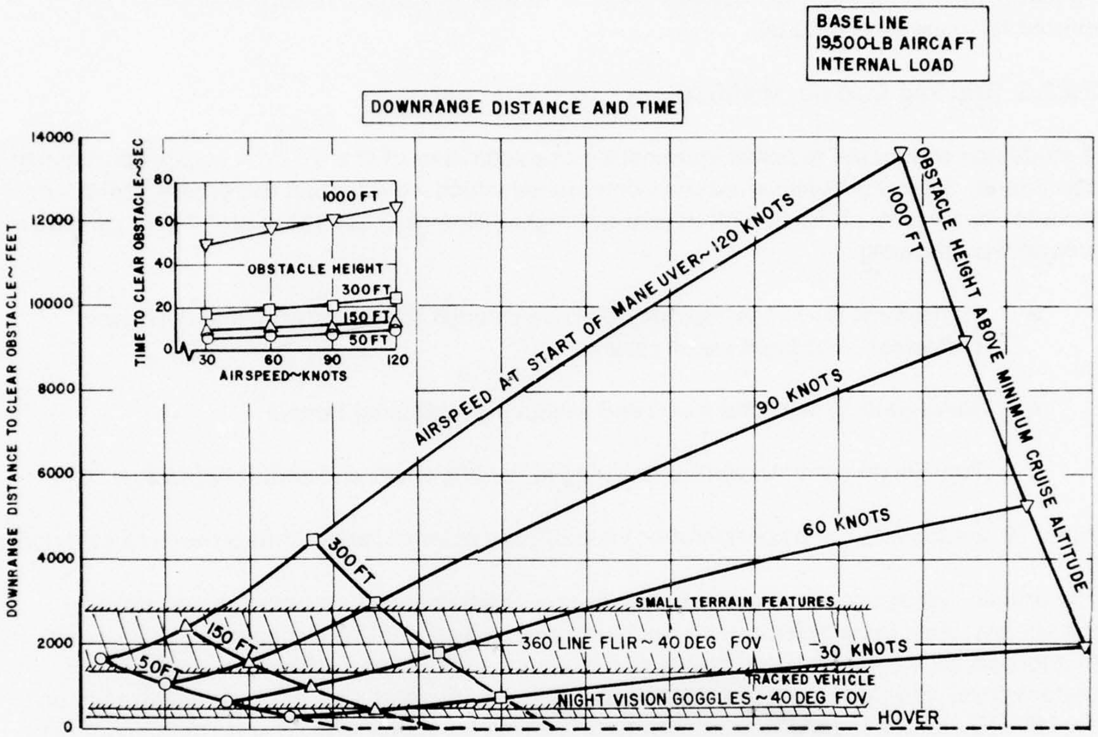

FIGURE 48. VERTICAL TERRAIN AVOIDANCE CAPABILITY WITH FLIR AND NVG VISIONIC SYSTEMS

to clear obstacle heights from 50 to 300 feet at corresponding airspeeds from 120 down to 30 knots. That is, as the obstacle height increases, the maximum permissible speed decreases. With FLIR, obstacle height vision capability for small terrain features varies from approximately 190 feet at 120 knots to well over 1,000 feet at 30 knots.

It is noted that these projected speeds may seem lower than some actual demonstrations. The 75-percent performance level, however, represents a more stringent environment than has existed for most tests to date.

3.3.2.3 Required Cockpit Modifications

A study was conducted to assess illumination characteristics of the UH-61A cockpit during night operations. Several problem areas were determined which would affect the general ability of the pilot to perform at night, with or without night-vision devices. These problem areas center around the following:

- Reflections leading to obstructed vision through the windshield, and decreased performance of night-vision systems
- Glare causing degraded vision and producing additional fatigue
- Poor instrument readability resulting in reading errors and additional fatigue.

Table 10 summarizes these considerations and defines potential areas of improvement or redesign.

The primary impact of these shortcomings is a potential degradation in the performance of the aircrew while using systems which aid or provide visual sighting during night/IMC conditions. In addition, an increase in pilot fatigue occurs which undoubtedly affects safety as well as performance. Problems of the type addressed in this table should be thoroughly explored on the UTTAS aircraft to ensure maximum terrain flying capability in night and IMC operations.

3.3.3 Flight Control/Handling Qualities

As previously discussed, UTTAS handling qualities can restrict hover and low-speed operations as illustrated in Figure 49, at night and in reduced visibility, particularly while using night-vision devices. The lack of peripheral visual cues makes the hovering task very demanding with the UTTAS rate control system. Control accuracy is probably not adequate for safe load acquisition in this environment.

Precision maneuver techniques for flight close to the ground require considerable pilot concentration and skill even in a VFR day environment. Addition of IMC or night requirements in a hostile environment adds a significant increment to the pilot workload. Figure 50 projects the relative magnitude of pilot effort required for terrain flying and precision hover. Increases of 100 percent can be expected for similar tasks when conducted during night operations.

TABLE 10. UH-61A COCKPIT CONSIDERATIONS FOR NIGHT VISIBILITY

PROBLEM	EFFECTS ON PERFORMANCE	CANDIDATE SOLUTIONS
WINDSHIELD REFLECTIONS CENTER WINDSHIELD INBD SIDES OF WINDSHIELDS DOOR WINDOWS	DEGRADES NIGHT EXTERNAL VISION FOR OBSTACLE AVOIDANCE OBSCURES OBSTACLES DECREASES OBSTACLE CONTRAST MAY IMPAIR EXTERNAL FOCUS AND ACUITY	• TURN OFF CENTER CONSOLE • RECONFIGURE THE GLARE SHIELD • APPLY LIGHT CONTROL TECHNIQUES
MAP READING	LIGHT FIXTURES FOR MAP READING DIFFICULT TO USE. RED LIGHT MAKES MAP READING DIFFICULT.	• RECONFIGURE MAP LIGHT
UNBALANCED LIGHTING ON CENTER CONSOLE	DIFFICULT TO MANAGE – NO OPTIMUM LIGHT LEVEL SETTING. AGGRAVATES THE WINDSHIELD REFLECTION PROBLEM.	• RECONFIGURE LIGHTING

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LIMITATIONS OF THE UTTAS HELICOPTER IN PERFORMING TERRAIN FLYIN--ETC(U)
SEP 77 I B ALANSKY, J M DAVIS, T S GARNETT DAAJ02-76-C-0027
UNCLASSIFIED D210-11226-1 USAAMRDL-TR-77-22 NL

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LIMITATIONS:

CONTROL ACCURACY

- HANDLING QUALITIES
  - RATE / ATTITUDE CONTROL RESPONSE
  - NO ALTITUDE HOLD
- NO PILOT-TO-LOAD VISIBILITY
- DRIFTING UNDETECTABLE IN LOW VISIBILITY

WEAPON PLACEMENT ACCURACY

- LOAD SUSPENSION
  - NO YAW RESTRAINT WITH SINGLE POINT
  - LOAD SWAY MODES LIGHTLY DAMPED

WORKLOAD VERY HIGH

- HANDLING QUALITIES
- REDUCED VISIBILITY
- HOOKUP SAFETY

FIGURE 49. LOAD ACQUISITION AND DEPOSIT

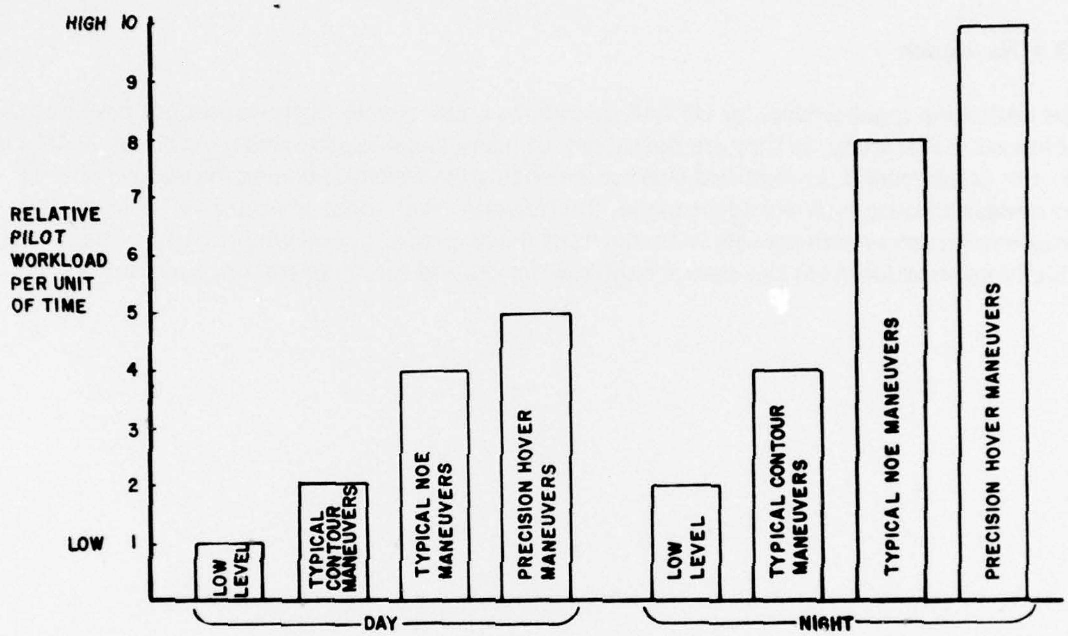

FIGURE 50. DAY/NIGHT COMPARISON OF RELATIVE PILOT WORKLOAD

Candidate solutions for the night/IMC handling qualities limitations that have been flight tested include the use of hover/approach displays with command symbology (Reference 16) or ground velocity control and stabilization techniques (Reference 17). Table 11 summarizes these systems, with advantages and disadvantages noted. Two ground velocity concepts are shown, with the second including a remote crewman control to aid low-visibility hookup. The ground-speed control system has significant advantages over the hover displays, as noted, and can be extended to include all low-speed maneuvering.

3.3.4 Navigation

The navigation requirements for UTTAS operations under terrain flight restrictions have not been addressed in this study, as they are the subject of many ongoing programs highlighted in Reference 18. For completeness, a simplified chart summarizing the tradeoffs among the various alternative navigation systems is reproduced from this reference, with some additions, in Table 12. The Doppler/compass system appears to be the most likely choice. As shown previously, the velocity information from this device is suitable for ground-speed control implementation.

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16. Milelli, R. J., Johnson, D. C., Tsoubanous, C. M., MANUAL PRECISION HOVER WITH SUPERIMPOSED SYMBOLOGY ON A FLIR IMAGE, AHS Paper 922, American Helicopter Society, Washington, D.C., May 1975.

17. Davis, J. M., HEAVY LIFT HELICOPTER – FLIGHT CONTROL SYSTEM FINAL REPORT – VOLUME III AUTOMATIC FLIGHT CONTROL SYSTEM, Boeing Vertol Report D301-10322-3, 24 June 1976.

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TABLE 11. NIGHT/IMC LOAD ACQUISITION HANDLING QUALITIES

CANDIDATES	ADDITIONAL SYSTEM COMPLEXITY	EFFECTIVENESS		ADVANTAGES	DISADVANTAGES
		CONTROL ACCURACY	WORKLOAD		
HOVER DISPLAY	TV DISPLAY COMMAND SYMBOLOGY – VELOCITY – ACCEL'N HOVER MOTION SENSOR – OPTICAL/IR TRACKER ELECTRONIC PROCESSING	ADEQUATE (<2 FOOT RMS)	HIGH		• NO WORKLOAD REDUCTION • INCOMPATIBLE WITH NIGHT VISION DEVICES AS MUST FOCUS ON DISPLAY
HOVER GROUND-SPEED HOLD SYSTEM WITH PILOT VERNIER CONTROL	DOPPLER/INERTIAL SENSOR ELECTRONIC PROCESSING FOR SCAS	ADEQUATE (<1 FOOT RMS)	LOW	• SIGNIFICANT WORKLOAD REDUCTION • IMPROVES CONTROL ACCURACY FOR – BOB UP/REMASK – TAKEOFF/LANDING • CAN USE DOPPLER REQD FOR NAVIGATION	
HOVER GROUND-SPEED HOLD SYSTEM WITH REMOTE CREWMAN CONTROL	ABOVE PLUS 3- OR 4-AXIS CONTROLLER FOR CREWMAN	ADEQUATE (<1 FOOT RMS)	LOW	ABOVE PLUS ADDITIONAL HOOKUP SAFETY	

TABLE 12. ALTERNATIVE NAVIGATION SYSTEMS			
REF: RPT 266-1 ANACAPA SCIENCES, INC.			
SYSTEM TYPE	FAVORABLE	UNFAVORABLE	COMMENTS
• VOR RADIO BEACONS • TACAN • DECCA	• LOW COST • LIGHTWEIGHT	• SHORT RANGE • MARGINAL ACCURACY • VULNERABLE TO ECM • MULTIPLE GROUND STATIONS • LINE-OF-SIGHT LIMITATIONS	
• OMEGA	• MODERATE COST • LIGHTWEIGHT • WORLDWIDE COVERAGE	• MARGINAL ACCURACY • VULNERABLE TO ECM • VULNERABLE TO PHYSICAL DESTRUCTION • VULNERABLE TO POLITICAL SHUTDOWN	
• NAVSTAR GLOBAL POSITIONING SYSTEM	• HIGHLY ACCURATE • WORLDWIDE COVERAGE	• NOT OPERATIONAL • VULNERABILITY UNKNOWN • COST UNKNOWN	
• LORAN C • LORAN D	• MODERATE COST • ACCURATE	• VULNERABLE TO ECM • VULNERABLE TO PHYSICAL DESTRUCTION • NEEDS CALIBRATION AND RATE-AIDING	
• INERTIAL	• SELF-CONTAINED, SECURE • PASSIVE	• HIGH COST, HIGH UPKEEP • HEAVY EQUIPMENT • TIME-DEPENDENT ERROR • NEEDS PREFLIGHT ALIGNMENT	
• AIR-DATA/COMPASS	• LOW COST • LIGHTWEIGHT • SELF-CONTAINED, SECURE • PASSIVE	• INACCURATE	
• DOPPLER/COMPASS	• MODERATE COST • SELF-CONTAINED • ACCURATE VELOCITY	• ACCURACY DEPENDS ON COMPASS • NEEDS GOOD MAG-VAR, COMPASS SWING • PROPAGATES SIGNAL	SELECTED FOR DEVELOPMENT BY ARMY
• INERTIAL STRAPDOWN	• SELF-CONTAINED, SECURE		
• OPTICAL CORRELATORS		• LACKS ADEQUATE RESOLUTION FOR NOE/ CONTOUR FLIGHT • REQUIRES PREPROGRAMMING	

4.0 SYSTEM DEFINITION

This section of the report describes Phase II work associated with preliminary design of a light-weight removable tandem hook beam conversion (Figure 43), and a single Active Arm External Load Stabilization System (AAELSS) concept (Figure 38) for UTTAS. Both systems have been designed and sized for the UH-61A aircraft, but either scheme (with minor modification) would be suitable for application on the UH-60A UTTAS helicopter as well.

4.1 TANDEM HOOK BEAM CONVERSION

4.1.1 System Application

The tandem hook beam converts the single point standard aircraft cargo hook installation for dual hook operation. This suspension mode has several advantages. By preventing the cargo from rotating in flight, which is a characteristic of most bulky single point loads such as CONEX containers, aircraft forward speed limits are increased, handling qualities and maneuverability are improved, and the ability to deposit the load accurately in azimuth is provided.

The tandem hook configuration is also very effective in preventing loads such as howitzers from striking the fuselage bottom when short slings are employed. Dual point artillery loads swing longitudinally in a more or less level attitude, instead of elevating the muzzle or trails at the peak of the sway arc (as on a single point suspension), which requires a reduction in maneuverability to prevent load strikes. This UTTAS tandem hook arrangement utilizes essentially the same type of load restraint as is provided with the tandem hook system that was test flown earlier on several CH-47 type aircraft (References 4 and 5), and is currently under development for future incorporation on the YCH-47D helicopter.

4.1.2 Design Criteria

Several criteria applied in preliminary development of the tandem hook beam conversion for the UH-61A helicopter were similar to those used during design of the basic aircraft cargo hook itself, except for load sharing requirements between the two hooks.

Structural guidelines followed in beam design included:

Design Load – 7,000 pounds

Load Split Between Hooks – 60 percent forward hook/40 percent aft
or 40 percent forward/60 percent aft

Limit Load Factor – 2.5g

Factor of Safety – 1.5

Permissible Load Sway Angle – 30 degrees any direction from vertical

Other criteria adopted in development of the beam were:

- GENERAL OPERATING REQUIREMENTS – The removable tandem hook beam system should be easily installed on the aircraft in minimum time. Electrical and mechanical

hook release systems should be provided through umbilical cables where practical, with appropriate interface quick-disconnect receptacles installed in the aircraft for power.

- BEAM SUSPENSION – The forward end of the beam should be installed in a rotatable load carrying receptacle, which automatically releases the beam when the aircraft main cargo hook is released. The forward receptacle should permit the beam to pivot laterally with the aircraft cargo hook, to follow lateral load sway out to ±30 degrees in either direction. Aft beam attachment to the aircraft is by means of the standard aircraft cargo hook.

- TANDEM HOOKS – Currently available lightweight production hooks, with both electrical and mechanical release capability, should be used. These are to be rigidly affixed to the beam so that no motion relative to the beam is possible.

- RELEASE MODES – Normal load release from the aircraft is to be configured to permit simultaneous electrical or backup mechanical operation of the tandem hooks. Emergency load jettison should be possible in any flight mode, by normal electrical operation of the aircraft main cargo hook.

- SUSPENSION FAILURE CONSIDERATIONS – Location of forward and aft tandem hooks with respect to permissible aircraft cg locations should be carefully selected to permit failure of either the forward or aft suspension, followed by retention of the load on the remaining sling, and then recovery of the aircraft through application of available longitudinal control. UH-61A hingeless rotor control power is adequate to handle such a failure with the hook locations selected, but hook spacing must be reviewed for application of the concept on other aircraft.

4.1.3 Design Features and System Use

Figure 43 shows a typical application of the tandem beam conversion on the UH-61A aircraft. The tandem suspension shown in the figure is supporting a 105mm howitzer and piggyback A-22 load, of the type flown in the terrain flying maneuver series for the UTTAS. This tandem hook arrangement would also be very effective with loads having strong aerodynamic characteristics such as CONEX containers and fuel bags which would tend to rotate on single point suspensions.

4.1.3.1 Design Details

Figure 51 illustrates detail design features incorporated into the UH-61A tandem hook conversion. The tandem hooks are mounted on the beam 90 inches apart, with the aft hook located about 20 inches behind the beam transverse pin and spacer connection to the aircraft cargo hook. The method of connecting the beam to the aircraft cargo hook is detailed in Figure 51, Section CC. With this hook closed, the spacer rides snugly on the hook throat and follows lateral sway motion as the hook swings from side to side. The main cargo hook is mounted in the aircraft so that no fore-and-aft motion of the hook is possible.

- Cargo Hooks – The cargo hooks selected for the beam are the Eastern Rotorcraft Model SP7109-12 installations shown in Figure 51. The hooks have manual release cables (not shown) which would be coupled to an emergency jettison handle installed on the beam

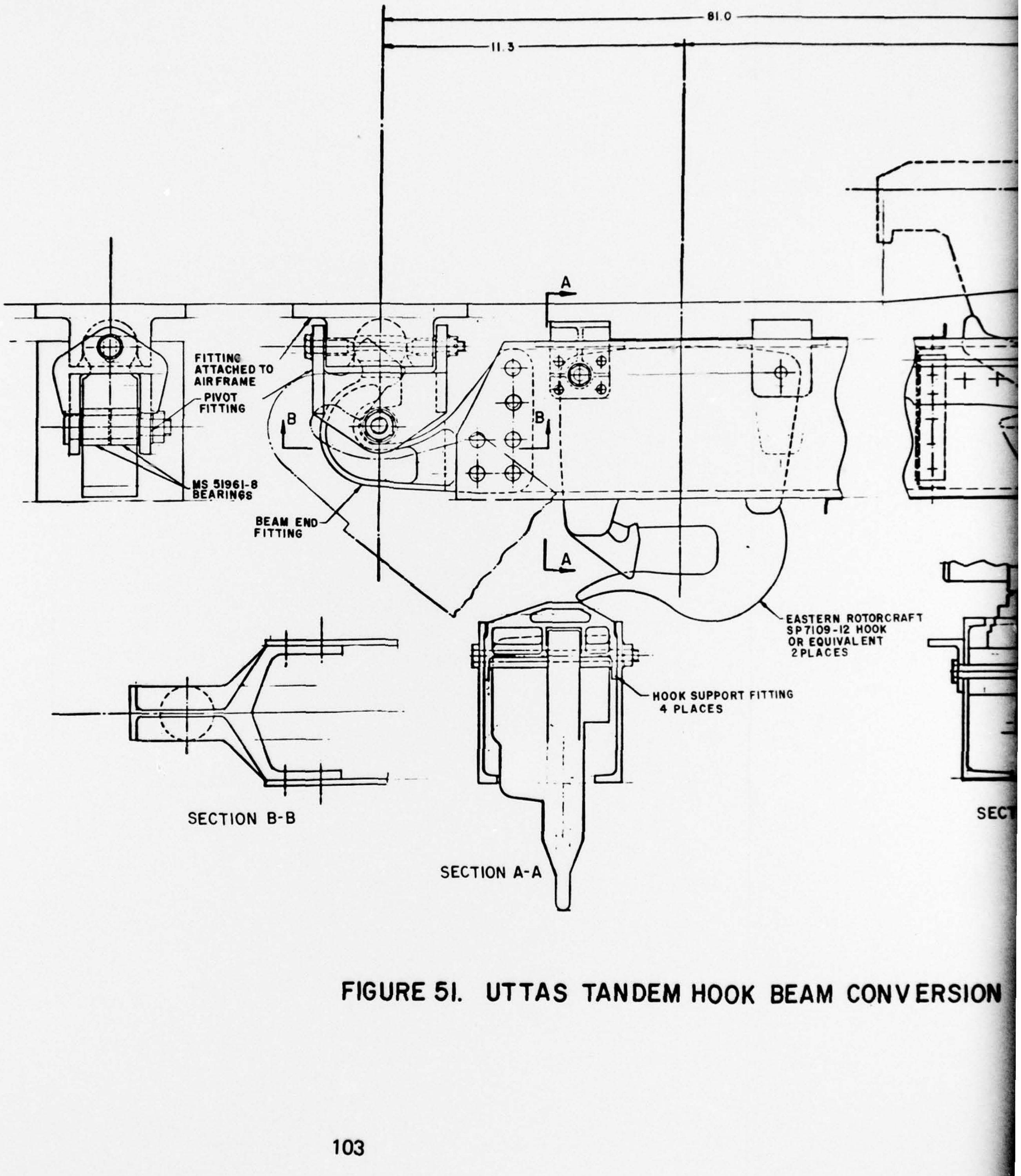
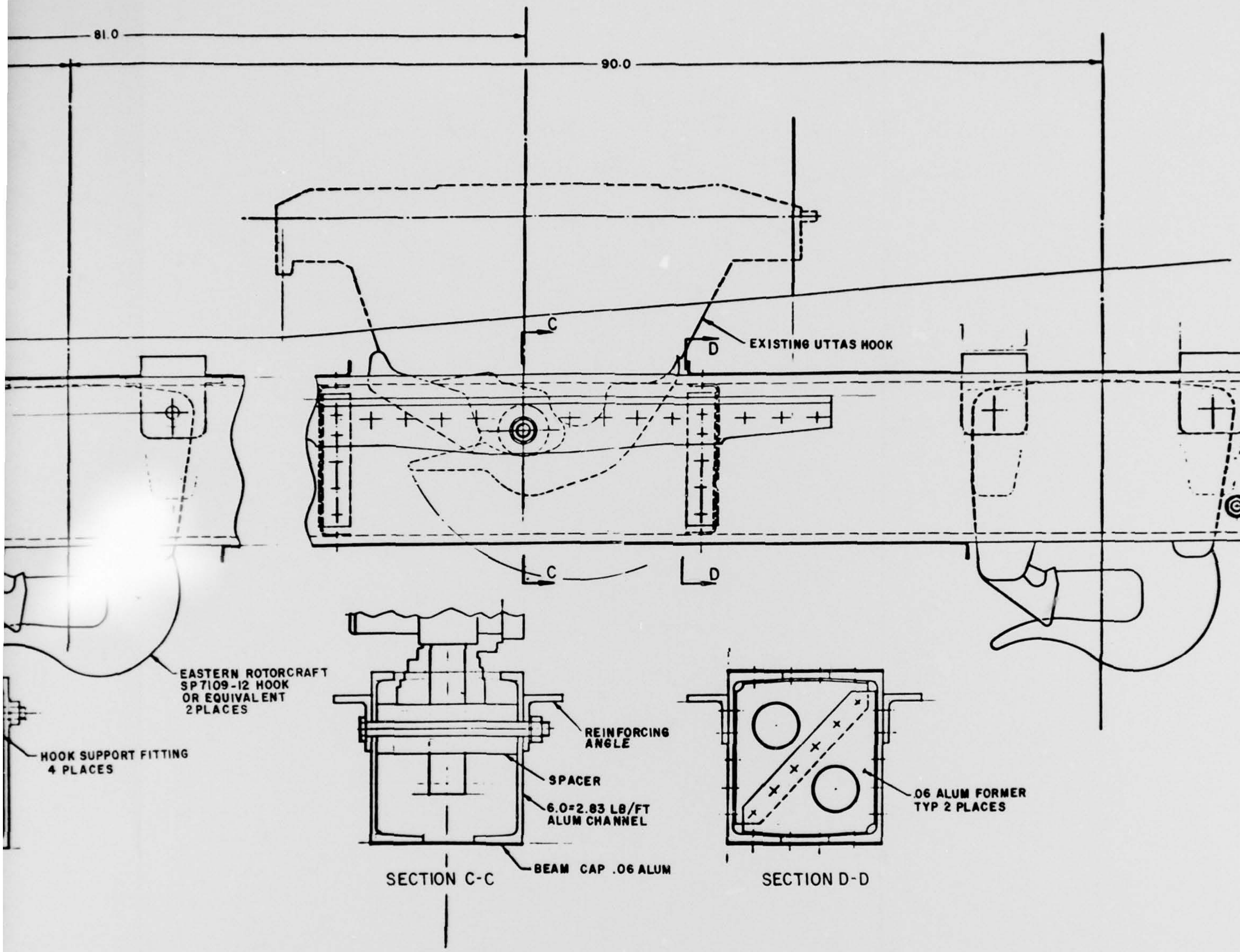


FIGURE 51. UTTAS TANDEM HOOK BEAM CONVERSION



NDEM HOOK BEAM CONVERSION

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adjacent to the aircraft cargo hook hatch. The normal hook release is effected electrically through a removable umbilical cable which connects the hook release solenoids to the aircraft DC electrical bus system, and has another cable running to a portable hand-held control box with a single release switch and a hook load status light.

- Forward Beam Attachment – The forward end of the beam rides on a laterally oriented horizontal pin arrangement, attached to the airframe through a pivot fitting and bracket, which is captured longitudinally by a curved shepherd's crook-like fitting on the beam with a spherical half-ball on its upper extremity (Section BB). In normal operation, the horizontal pin pivot fitting is free to swing laterally on the attachment bracket, so that the beam follows sideward load sway. The upper end of the shepherd's crook half-ball rides in a spherical recess in the portion of the attachment bracket bolted to the aircraft. This bracket keeps the beam aligned with the horizontal pin, so that vertical loads are transferred from the beam through the pin into the airframe, and longitudinal loads are taken out through the half-ball into the bracket itself.

- Emergency Jettison – For emergency jettision of the beam, the main cargo hook is released and the aft end of the beam rotates downward. As shown in the side view of the beam front end attachment, after about 30 degrees of rotation the shepherd's crook fitting will ride off of the horizontal pin, and the beam is free to drop. The pin rotates on MS51961-6 bearings to prevent friction loads from hanging up the beam during the jettison sequence. Alternative front end configuration concepts, involving electromechanical and pyrotechnic bolt release systems,were discarded in favor of the simple shepherd's crook approach, because of the difficulty in achieving simultaneous main cargo hook and front end attachment release capability with those schemes.

4.1.4 System Weight Breakdown

Table 13 presents an estimated weight breakdown for a prototype UTTAS tandem hook beam conversion for the UH-61A helicopter. The system is very light (132 pounds) and would be fabricated from commercially available 6061 T-6 aluminum channel elements, with aluminum fittings and AN/NAS hardware fasteners used as required. A minimal amount of backup structure is required in the aircraft to carry the forward beam end attachment bracket loads.

For any UTTAS production application, the weight of the beam conversion could undoubtedly be reduced somewhat by using lightweight materials.

4.2 SINGLE REMOVABLE ACTIVE ARM EXTERNAL LOAD STABILIZATION SYSTEM

4.2.1 Design Concept

A single AAELSS concept has been developed for application on UTTAS-type single rotor helicopters, configured with a cargo hook hatch in the fuselage bottom. A sketch of the concept installation is shown in Figure 38, with a 105mm howitzer and piggyback A-22 bag being carried on modified tandem slings. The single arm UTTAS approach, with close-coupled tandem hooks for limited yaw restraint, is an outgrowth of two earlier systems flight-tested on CH-47-type aircraft and discussed in References 4 and 5.

TABLE 13. TANDEM HOOK CONVERSION WEIGHT BREAKDOWN	
REMOVABLE	
BEAM ASSEMBLY	76.6 POUNDS
HOOKS (2 AT 15.1 LB)	30.2
CONTROL SYSTEMS	12.0
FWD PIVOT FITTING	2.0
	120.8 POUNDS
FIXED PROVISIONS	
STRUCTURAL BACK-UP	7.0
FUSELAGE ATTACH FITTING	4.0
	11.0 POUNDS
SYSTEM TOTAL	131.8 POUNDS

A dual arm AAELSS is also proposed as an alternative solution for improving CH-47 masking and aircraft maneuverability for terrain flight. The development of this dual arm lightweight AAELSS was conducted under the CH-47 terrain flying study discussed in Reference 3.

Limited single arm AAELSS development was carried out to define schemes for driving the arm, retracting the lower section, and limiting yaw excursions of the load.

- Arm Configuration – The system shown in Figure 38 would be designed to structural criteria identical to that described earlier for the tandem hook beam in Section 4.1.2. As envisioned, the arm structure would be suspended at its top (on a universal joint), from a removable framework bolted to the aircraft floor tiedown studs.

  The cylindrical hollow arm would contain a telescoping T-shaped lower section held against the aircraft lower surface (before the load is picked up) with an internal compression spring.

  Once the cargo is attached, and slack taken out of the suspension slings just prior to load liftoff, the lower T-bar extends downward (as shown in the figure) into a locked detent position that prevents yaw rotation of the lower horizontal section.

- Arm Drive and Control – The arm is driven by longitudinal and lateral hydraulic actuators powered either from the aircraft utility hydraulic system (if adequate flow capacity is available), or from an integral electrically driven hydraulic pump and supply mounted on the attachment frame. Actuator cylinders are located in a horizontal plane, and are attached to the arm near aircraft floor level.

  Arm and cargo hook sway angle information is developed from sensors mounted at the top of the arm, and on both hooks. Load and arm angle information is processed in a self-contained automatic AAELSS control system using AC and DC electrical power from the aircraft, but control laws separate from the SCAS, to command arm motion for load damping as described in Reference 5. As indicated in the reference, load motion damping levels of 30 percent of critical are adequate for satisfactory flying qualities with external loads.

4.2.2 System Weight

Based on estimated detail weight breakdown calculated for the CH-47 in Reference 3, it is expected that a single arm UTTAS AAELSS would weigh between 300 and 350 pounds. Most of this weight would be removable from the aircraft, as the system controls, hydraulic drives, etc.,are mounted on the arm attachment frame structure.

4.2.3 Single Arm AAELSS Application

As indicated in Section 3.3, automatic load stabilization has the potential for reducing load sway motion by 2/3 and for eliminating PIO tendencies in reduced visibility conditions to levels which produce handling qualities approaching those of an internally loaded aircraft. At the present time, however, very little external cargo work has been done with UTTAS aircraft, and the requirements for automatic load stabilization have not been verified in flight test.

Hardware development of the concept should be pursued after field experience with external cargo (especially in terrain flight maneuvering or during night/IMC operations) has verified the need for load stability augmentation as shown in this report. Further design studies need to be accomplished.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Results obtained from this study have determined that addition of an external load need not reduce the effectiveness of the UTTAS helicopter as an assault vehicle on the mid-intensity battlefield. The UTTAS exhibits a good terrain flight potential with external loads, when limitations associated with current suspensions are alleviated. These limitations include:

1. Masking constraints as a result of sling lengths
2. Maneuverability restrictions due to load motion and load/aircraft collisions
3. Speed restrictions due to load instability or drag increase

Cargo suspension system concepts identified to minimize the current deficiencies include shortened suspension lengths, automatic load stabilization, and a tandem hook beam conversion for the aircraft cargo hook. Conclusions relative to these concepts are:

1. Short suspensions improve terrain flight masking, but also reduce the maneuvering capability.
2. Active load stabilization can be used with the short suspension to restore aircraft maneuverability. It also removes potential limitations occurring in night/IMC operations due to pilot induced oscillations, and reduces pilot workload.
3. Contour and low level speed capability can be improved for aerodynamically unstable loads (such as the CONEX container) with the tandem hook beam conversion. Longitudinal maneuverability is also improved.

A preliminary design study of the two most effective candidate concepts, including a single Active Arm External Load Stabilization System and a Tandem Hook Beam Conversion Device shows that the weight penalty for the tandem hook beam approach is about 1/3 of the AAELSS weight (130 pounds vs 350 pounds). The advantages and disadvantages of each approach are discussed in Section 3.3.1. Both concepts should be carried forward to a terrain flight demonstration.

The utilization of UTTAS in the terrain flight environment at night, or in reduced visibility, requires solutions for the following additional limitations:

1. Pilot visibility for flight path control and obstacle avoidance
2. Pilot-induced oscillations incurred by low damping of load disturbances
3. Inadequate hover accuracy for load acquisition/placement
4. High pilot workload levels during hover/NOE/contour maneuvers.

Analysis and/or flight experience with tandem helicopters has shown that the load stabilization system has the potential for removing the PIO susceptibility as a flight limitation in low visibility conditions.

Improvements in pilot night vision can be achieved either through the use of night vision goggles (NVG) or a forward-looking infrared (FLIR) system. NVG provide a limited NOE/ contour maneuver capability up to approximately 30 knots, whereas FLIR can provide a visual capability permitting NOE/contour maneuvering to 60-80 knots. For wire avoidance, the Laser Obstacle Terrain Avoidance and Warning System (LOTAWS) possesses a wire detection range compatible with FLIR, and in conjunction with FLIR provides for safer night/IMC terrain flying.

Incorporation of ground velocity stabilization and control (derived from 347/HLH concepts) offers a high potential for reducing pilot workload during hover and low speed flight, while providing the necessary control accuracy for cargo acquisition and placement. The lightweight Doppler navigation system currently under development by the U.S. Army can be used as the velocity signal source. As the Doppler system also appears to be required for terrain flight navigation, no additional sensor costs are incurred.

5.2 RECOMMENDATIONS

Fulfillment of the potential around-the-clock, external load terrain flight capability of the UTTAS requires continued development and evaluation of modifications to the cargo handling and flight control systems and incorporation of visionic/obstacle avoidance systems. The following recommendations do not address visionics, as that development is being conducted for the Advanced Attack Helicopter.

5.2.1. Recommended Cargo Handling Programs

1. Conduct short-suspension-restraint flight testing on a UTTAS helicopter to verify the reduced maneuverability and PIO susceptibility boundaries in NOE and contour flight modes.
2. Design, fabricate and flight test a Tandem Hook Beam Conversion for the UTTAS aircraft.
3. Continue design of a single Active Arm External Load Stabilization System. Hardware development and flight test should await the results of subparagraph 1, above.
4. Explore the feasibility of maximizing terrain flight masking and maneuverability with external loads, through the use of load snubbing against the aircraft bottom. Conduct preliminary design trade studies to size and determine the potential costs of prototype concept implementation.

5.2.2 Recommended Flight Control System Programs

1. Conduct a piloted flight simulation program to establish stability and control augmentation system concepts suitable for NOE/contour flight under reduced visibility. Stability and control improvements represent the only viable approach to workload reduction in this environment.
2. Design and flight test a control system using groundspeed stabilization concepts, with the lightweight Doppler navigation system providing the necessary signal source. Evaluate in the hover and terrain flight modes.

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